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GEOLOGICAL SURVEY OF VIRGINIA

THOMAS L. WATSON, GEOLOGIST IN CHARGE

GEOLOGICAL SERIES, BULLETIN NO. II.

The Clay Deposits of the Virginia Coastal Plain

BY

HEINRICH RIES

WITH A CHAPTER ON

The Geology of the Virginia Coastal Plain

BY

WILLIAM BULLOCK CLARK
and
BENJAMIN LEROY MILLER

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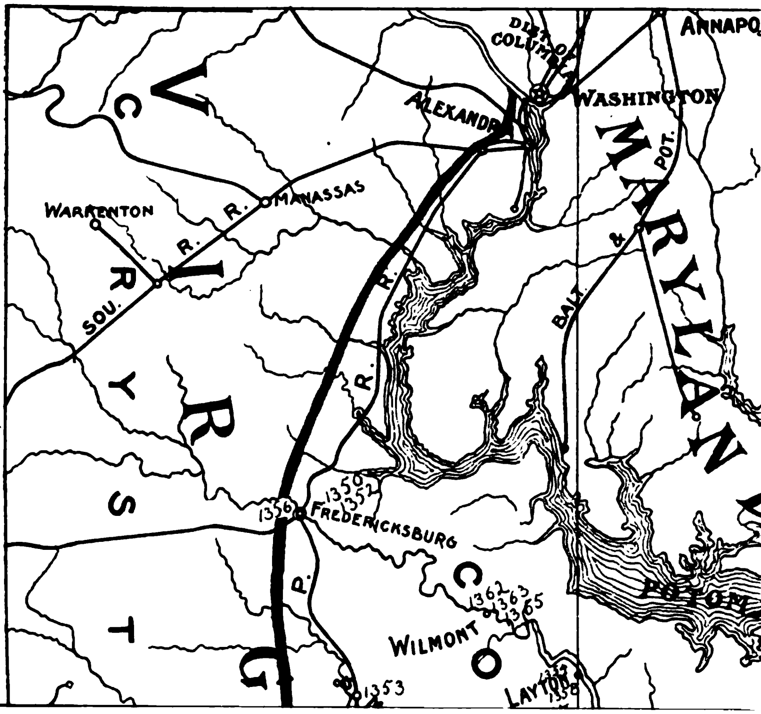
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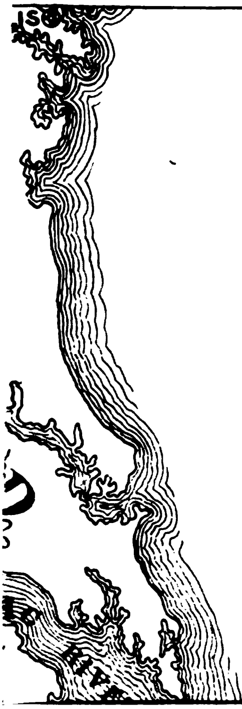

Map of the Virginia Coastal Plain

SHOWING CLAY LOCALITIES

Scale 18 Miles=1 Inch

VIRGINIA GEOLOGICAL SURVEY

Thomas L. Watson, Geologist in Charge.

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Red figures indicate locality of clay samples tested
Heavy red line represents the Fall-Line.

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LETTER OF TRANSMITTAL

To the Members of the Virginia Board of Agriculture and Immigration, and the Board of Visitors of the Virginia Polytechnic Institute:

Gentlemen—I have the honor to submit herewith a report on the Clay Deposits of the Virginia Coastal Plain, by Dr. Heinrich Ries, Assistant Professor of Economic Geology in Cornell University; and to request that it be published as Volume II of the Geological Series of the Virginia Survey.

Respectfully.

THOMAS L. WATSON,

Blacksburg, Va., March 15th, 1906. Geologist in Charge.

PREFACE

The present volume forms Bulletin No. II of the series of reports issued on the economic geology of Virginia, under the co-operation of the State Board of Agriculture and the Board of Visitors of the Virginia Polytechnic Institute.

This report is based on field work carried on during the summer of 1905. The investigation was limited to the clays of the Coastal Plain Area or the Tidewater Belt of Virginia. Beginning with the next field season, it is expected that this work will be extended as rapidly as possible to all portions of the State and, when completed, a final volume will be issued on the clays and clay industry of the entire State.

The investigation of the Virginia clays was undertaken for the purpose of determining (1) the extent, qualities, and applicability of the clays; and (2) whether the clays now being utilized could be used for making other or better products than are now being made from them. This is fully covered for the Coastal Plain clays in the summary given by Dr. Ries under *Clay Working Industry of the Virginia Coastal Plain and Its Future Tendency,* on pages 175 and 176 of this report, to which the reader is especially referred. In the prosecution of the field work a large number of samples of the clays were collected from the various deposits and submitted to careful chemical and physical investigation, the results of which are given in Part II, Chapter V of this report.

The Geology of the Virginia Coastal Plain, by Dr. Wm. Bullock Clark and Dr. Benjamin LeRoy Miller, forms Part I of the report. It is a brief summary of our present knowledge of the Virginia Coastal Plain stratigraphy, and was prepared to be used as a basis or guide in the correlation of the various clay deposits described by Dr. Ries in Part II, Chapter V. A report, treating in considerable detail of the Virginia Coastal Plain stratigraphy, prepared under the direction of Dr. Clark, is nearly completed and will be published as a separate report by the Virginia Survey.

In Part II, Chapters, II, III, and IV, Dr. Ries discusses in considerable detail the origin, mode of occurrence, physical and chemical properties of clay; the methods of exploiting, mining, and preparation of clay; and the methods of manufacture of the different clay products, with particular reference to the Virginia Coastal Plain clays. A detailed description of the Coastal Plain clays is given in Chapter V, including their chemical and physical properties and uses, summarized by counties.

The large number of complete chemical analyses of the clays described in the report were made by Mr. John R. Eoff, Jr., and Mr. James H. Gibboney, assisted by Mr. D. D. Spiller, in the laboratories of the Virginia Polytechnic Institute, at Blacksburg. The physical tests made of the same clays, including air shrinkage, fire shrinkage, color in burning, temperature of vitrification, and of fusion, etc., were carried out under the immediate direction of Dr. Ries in his laboratory at Cornell University, Ithaca, N. Y. Mr. Henry F. Day, a student in geology at the Virginia Polytechnic Institute, served as field assistant to Dr. Ries during the season's work.

THOMAS L. WATSON,
Geologist in Charge.

Part I

A BRIEF SUMMARY OF

The Geology

of the

Virginia Coastal Plain

By WILLIAM BULLOCK CLARK
and BENJAMIN LE ROY MILLER

CHAPTER I.

THE GEOLOGY OF THE VIRGINIA COASTAL PLAIN.

INTRODUCTION.

The Virginia Coastal Plain is an area of low relief that slopes gradually from the Piedmont hill country to the ocean border, beyond which it is represented in the shallow sea floor that declines gently to the margin of the continental shelf. The submarine division is not materially different from the subærial division and has often stood above the sea level, the coast line having shifted its position in successive geological periods all the way from the Piedmont border far out toward the edge of the continental shelf where the ocean bed falls rapidly to the greatest depths.

The great body of deposits forming the Coastal Plain has been laid down along the border of the Piedmont on the floor of crystalline rocks of which that district is composed. At first estuarine in character, these sediments were later of marine origin and continued to be chiefly such until the later geological epochs, when the surficial deposits of the Pleistocene were laid down in the enclosed bays and estuaries of the dissected Coastal Plain district. As the sea stood at different elevations throughout this partially eroded area, a series of terraces were developed similar in character to that now forming along the margin of the tidal bays and streams that penetrate the Coastal Plain in all directions and give to the country the name of "tide-water" Virginia. Farther up the streams flood-plain deposits were laid down, most of which have disappeared as the result of erosion in the subsequent elevations of the area.

Across the district stretches the great estuary of the Chesapeake Bay, which finds its outlet seaward between Capes Charles and Henry. This sheet of water, so broad and deep today, affords the great highway of commerce for Virginia's export trade as well as the unparalleled local transportation facilities for the tide-water country. It occupies the lower valley of the old Susquehanna River which flowed across Maryland and Virginia and

found its way seaward, past the Capes, its channel being traced today across the sea floor of the submarine portion of the Coastal Plain. Its many tributaries, among them the Potomac, Rappahannock, York, and James Rivers, give access to vessels as far as the Piedmont border, widely known in geological literature as the "fall-line," since at this point the swiftly flowing streams of the Piedmont change rapidly, their strong currents becoming lost in the tidal estuaries.

Although composed of a succession of formations which represent nearly every period from the Jurassic to the Recent, the Coastal Plain deposits do not succeed each other in a conformable series, nor do they possess the same strikes and dips. A differential movement, at times pronounced and materially influencing the attitude of the beds, has so affected the district that transgressions have occurred, eliminating in certain sections the landward exposures of whole formations that appear in adjacent regions. Thus the upper Cretaceous deposits, so well exhibited in Maryland, are gradually transgressed by the Eocene southward, shutting out the former throughout the entire area of outcrop in Virginia although recognized in the deep-well borings at Fortress Monroe.

The deposits of the Coastal Plain for the most part consist of unconsolidated beds of sand, gravel, clay, and marl which may be locally indurated by the presence of a cement either of iron oxide or carbonate of lime. At times these indurated ledges serve as sources of building stone for local uses, and in one instance, viz., near Aquia Creek, the oldest formation of the Coastal Plain series has afforded stone suitable for export, this material having been employed for building purposes in Washington before the days of railroad transportation.

In general the beds strike from north to south, although some variation occurs as above explained. The strata have a general easterly dip which changes from 30 feet to the mile in the lowest formations—about the slope of the crystalline floor on which the deposits rest—to less than five feet to the mile in the highest deposits. With this relatively low dip the beds generally appear horizontal in any given section and may be actually so locally, so that measurements must be extended over a wide area before the average dip of any particular formation can be determined.

Along the eastern margin of the Piedmont district outliers of the Coastal Plain formations are frequent, while along the valleys of the larger streams the crystallines can at times be followed for some distance into the body of the Coastal Plain sediments where the mantle of the latter has been cut through.

THE FORMATIONS.

The formations comprising the Virginia Coastal Plain are given in the following table:

FORMATIONS OF VIRGINIA COASTAL PLAIN.

Cenozoic			
Quaternary			
	Recent		
	Pleistocene	Talbot Wicomico Sunderland	Columbia Group
Tertiary			
	Pliocene	Lafayette Norfolk	
	Miocene	Yorktown St. Mary's Choptank Calvert	Chesapeake Group
	Eocene	Nanjemoy Aquia	Pamunkey Group
Mesozoic			
Cretaceous			
	Lower Cretaceous	Patapsco	Potomac Group
Jurassic?			
	Upper Jurassic?	Arundel Patuxent	Potomac Group

THE JURASSIC (?) PERIOD.

Upper Jurassic?

The Patuxent Formation.

The Patuxent formation, so called from Patuxent River, Maryland, where the deposits are well exposed, constitutes the basal portion of what was originally described as the Potomac formation but which is now known to comprise several distinct stratigraphic units. The Patuxent formation has only been recognized

in the Chesapeake Bay drainage basin in Virginia and Maryland although it may exist farther southward. To the northward in New Jersey it has been overlapped by later deposits. In Virginia the formation is found near the head of tide in the leading drainage basins directly overlying the floor of crystalline rocks.

The deposits consist chiefly of sand, sometimes quite fine and gritty, but generally containing a considerable amount of kaolinized feldspar producing a clearly defined arkose. Sandy and plastic clays also occur, the latter commonly of light color, but often highly colored and locally not unlike the variegated clays of the Patapsco formation. The Patuxent formation includes the James River series and part of the Rappahannock series of Ward, and has a thickness of 250 to 300 feet. The fossils consist of plant remains, among which the cycads are the most distinctive. A few primitive dicotyledons also occur.

The Arundel Formation.

The Arundel formation, so named from Anne Arundel County, Maryland, is but poorly shown in Virginia, its maximum development occurring in Maryland. Certain clays in the vicinity of Mt. Vernon are thought to represent this formation. Further study of the Virginia region may result in the discovery of additional beds of this age.

The deposits consist of dark clays generally highly lignitic and in Maryland often carry large quantities of nodules of iron carbonate. The beds are thought to represent swamp accumulations in warped valleys of post-Patuxent time. The fossils are highly significant, since they consist in part of dinosaurian remains that are regarded by many vertebrate paleontologists as affording proof of the Jurassic age of the deposits, although the paleobotanists regard the beds as Lower Cretaceous. The plant remains are, however, not distinctive and the flora could with almost equal propriety be classed as Jurassic. For the present, therefore, the Arundel formation, together with the Patuxent which underlies it, is questionably referred to the Jurassic and assigned to its upper division.

THE CRETACEOUS PERIOD.

Lower Cretaceous.

The Patapsco Formation.

The Patapsco formation, so called from the Patapsco River in Maryland, overlies the Patuxent and Arundel formations unconformably. It has been traced in a broad belt across Maryland and Virginia and is found in isolated remnants to the northward in Delaware and Pennsylvania. Its southward extension has not been studied.

The deposits consist largely of highly-colored and variegated clays that grade over into lighter-colored sandy clays, while sandy bands of coarser character are at times interstratified. The sandy beds are sometimes arkosic and often carry clay lumps. The formation has a thickness of about 150 feet and dips about 30 feet in the mile to the eastward. The fossils are chiefly plants, among which many dicotyledons are found, and the formation is unquestionably Lower Cretaceous in age.

The Patuxent, Arundel, and Patapsco formations, together with the Raritan formation of Maryland, Delaware, and New Jersey, constitute the Potomac group.

The Raritan, Magothy, Matawan, Monmouth, and Rancocas, formations, the last three representing the greensand series of New Jersey south of Delaware Bay in Delaware and Maryland, are gradually transgressed one after the other by the Eocene deposits to the southward, and have not been found along the line of outcrop south of the Potomac River in Virginia. The Cretaceous greensands have been penetrated in the deep wells at Fortress Monroe so that some at least of these absent formations are buried beneath the later deposits farther to the eastward in the Virginia Coastal Plain.

THE TERTIARY PERIOD.

Eocene.

The Aquia Formation.

The Aquia formation, so called from Aquia Creek in Stafford County where the most conspicuous section of the deposits of this

horizon occur, first appears beneath the northward transgressing Miocene deposits near the Delaware-Maryland line from which point it extends across Maryland into Virginia where it rests unconformably on the Patapsco formation.

The deposits consist of greensands and greensand marls, the latter often holding great quantities of molluscan shells that afford at times a cement which causes the beds to be indurated into hard limestone ledges. Beds of clay occur but are less conspicuous than in the overlying Nanjemoy. The formation has a thickness of about 100 feet in the Potomac River region where it dips to the eastward at somewhat less than 15 feet to the mile. The fossils are numerous and distinctive, most of the important groups of animal life being represented, the marine mollusca predominating. The deposits are of undoubted Eocene age.

The Nanjemoy Formation.

The Nanjemoy formation, so called from Nanjemoy Creek, in Maryland, is first recognized on the western shore of Maryland in Anne Arundel County, from which point it stretches across the state into Virginia and has been recognized as far south as the James River basin. The deposits rest conformably on those of the Aquia throughout the area.

The Nanjemoy, like the Aquia formation, consists largely of greensands but at the same time contains a larger element of argillaceous materials, the basal bed known as the Marlboro clay extending from central Maryland across the Potomac into Virginia. This clay bed consisting of 25 feet of compact clay, the lower part pink in color, the upper white, is well developed between Potomac Creek and the Rappahannock River. The Nanjemoy formation has a thickness of about 125 feet and has a dip of from 12 to 15 feet in the mile to the eastward. The fossils are numerous and distinctive and consists, as in the Aquia formation, largely of marine mollusca of characteristic Eocene types.

The Aquia and Nanjemoy formations together constitute the Pamunkey group which is now recognized to consist of two clearly defined formations which can be readily traced across the region.

Miocene.

The Calvert Formation.

The Calvert formation, so called from Calvert County, Maryland, in which region the deposits of this horizon are well exposed, along the high cliffs of the Chesapeake Bay, is first recognized in southern New Jersey, from which point it extends across Delaware and Maryland into Virginia. To the north of Maryland the Calvert formation rests directly on the Upper Cretaceous deposits by the overlapping of the Eocene northward, but south of the Delaware-Maryland line it overlies first the Aquia and then the Nanjemoy formation from central Maryland southward into Virginia.

The deposits consist chiefly of clays, sands, and diatomaceous earth. The clays are commonly sandy and at times highly calcareous but the latter less frequently appear as indurated ledges than in the Eocene. The diatomaceous earth is especially well developed in the lower part of the formation, although occurring in greater or less amounts in the upper beds and at higher horizons in the Miocene. Diatomaceous earth consists of the remains of vast numbers of diatoms which are miscroscopic plant forms with siliceous tests. This material which has been worked at many points is known in the trade as "infusorial earth," "tripoli," or "silica." It has also been called "Richmond earth" and "Bermuda earth," from localities in Virginia. The Calvert formation has a thickness of 150 to 200 feet and a dip of about 10 feet in the mile to the eastward. The fossils of the Calvert formation consist of the remains of marine organisms, chiefly mollusca, which are characteristically Miocene.

The Choptank Formation.

The Choptank formation, which receives its name from the Choptank River in Maryland, overlies the Calvert formation unconformably and gradually transgresses the latter northward, and in New Jersey rests directly on the Upper Cretaceous deposits. This formation is prominently exposed in southern Maryland and Virginia, outcropping in a nearly complete section in the Nomini Bluffs on the Potomac River.

The deposits consist of clays, sands, and diatomaceous earth, the sands being more largely developed than in the underlying Calvert formation. The clays are sandy and frequently calcareous. The diatomaceous earth is more prominent at this horizon than in the same formation in Maryland. The formation has a thickness of about 125 feet and the beds dip to the eastward at about 10 feet in the mile. The fossils are largely marine mollusca and although many of the same species occur in the Calvert formation, other and characteristic forms are found.

The St. Mary's Formation.

The St. Mary's formation, so called from St. Mary's County and river, Maryland, is buried beneath the Pleistocene cover in New Jersey, Delaware, and the Eastern Shore of Maryland, but outcrops in the bluffs of the Chesapeake Bay and its tributaries in lower southern Maryland and across the central district of the Virginia Coastal Plain. The formation overlies the Choptank formation conformably.

The deposits consist primarily of clays and sands, the former often blue in color and rich in calcareous matter from the disintegrated molluscan shells that often fill the beds. This shell marl has been employed for agricultural purposes. The formation is about 150 feet thick and has a dip of about 10 feet in the mile to the eastward. The fossils are chiefly marine mollusca as in the other Miocene formations although many representatives of other classes of animal life are found.

The Yorktown Formation.

The Yorktown formation, which receives its name from Yorktown, Virginia, apparently overlies the St. Mary's formation conformably. The infrequent exposure of the beds, due to the heavy cover of later sediments, renders it difficult to determine many of its characteristics and its entire area of outcrop. It does not appear at the surface in Maryland, although, perhaps, part of the great thickness of Miocene beds penetrated in the Crisfield well should be assigned to this formation.

The deposits which consist of sands and clays are crowded with remains of calcareous shells, chiefly marine mollusca, and at Yorktown and on the James River afford the most highly fossiliferous beds in the Chesapeake Bay region. Thick beds almost entirely composed of broken shells, representing shallow-water deposition, form the most striking feature. The thickness of the formation is apparently in excess of 100 feet. The fossils show certain differences when compared with the underlying Miocene formations, and evidently represent a distinct faunal aggregate.

The Calvert, Choptank, St. Mary's and Yorktown formations combined constitute the Chesapeake group. The deposits have many common characters, both physical and faunal.

PLIOCENE.

The Norfolk Formation.

The Norfolk formation, so called from Norfolk County, Virginia, where the deposits have been recognized in the deep cutting in the Dismal Swamp Canal, probably forms the northward extension of the Pliocene beds of North Carolina where the strata of this age are much more extensively developed than in Virginia. The deposits are buried beneath a heavy mantle of later Pleistocene sediments so that the areal extent and thickness cannot be readily determined. To the northward, in southeastern Maryland, if the deposits occur they must be deeply buried beneath the Pleistocene.

The deposits consist of clays and sands, the physical characteristics of the material being not unlike the Miocene strata beneath. In places the sandy clays, as in the canal cuts below Portsmouth, contain great quantities of shell remains, making the beds distinctly calcareous. The formation probably does not reach a thickness of 50 feet in Virginia. The fossils are chiefly marine mollusca of characteristic Pliocene types.

The Lafayette Formation.

The Lafayette formation, so named from Lafayette County, Mississippi, has been traced as a nearly continuous mantle over the older members of the Coastal Plain series all the way from the Mississippi

valley, parallel with the Coastal border, to Virginia, and southern Maryland, north of which the deposits become less extensive and are represented in northern Maryland, Delaware, and Pennsylvania by only a few small remnants. In Virginia a broad belt extending from the Piedmont margin to the center of the Coastal Plain is covered by a mantle of Lafayette deposits in the interstream areas.

The deposits consist of clay, loam, sand, and gravel, the latter often highly ferruginous, and cemented into a compact iron-stone. The sediments were much less fully sorted than was the case in the earlier Tertiary formations, although the coarse sandy and gravelly materials are most common in the lower part and the loams most common in the upper part of the formation. The gravel, too, is often considerably decayed. The deposits frequently possess a characteristic orange color. The Lafayette formation has an average thickness of about 50 feet, but at times exceeds 75 feet.

A few fragments of molluscan shells have been reported from eastern Virginia but they are quite inadequate to determine the age of the deposits if they should ultimately prove to have come from beds of this horizon. The reference of the beds therefore to the Pliocene is based on the fact that they have been found overlying the Miocene, and that they are in turn older than the Columbia deposits of Pleistocene age which wrap about their margin. The discovery of authentic fossils of chronologic value is therefore necessary before the correlation can be regarded as satisfactory.

THE QUATERNARY PERIOD.

PLEISTOCENE.

The Sunderland Formation.

The Sunderland formation, so called from Sunderland, Calvert County, Maryland, wraps as a terrace about the Lafayette or, in case of its absence by erosion, the older formations of the Coastal Plain area throughout the middle Atlantic region. At the close of the Lafayette epoch the Coastal Plain region was elevated and the main drainage channels of the area were deeply cut, the coast

line standing far to eastward of its present position. The great Susquehanna River flowed through the channel now occupied by Chesapeake Bay, and passing the Capes, reached the sea far to the eastward.

With the advent of Sunderland time the sea filled the old channels far above the present level but fell short of the greater elevations of the western Coastal Plain district. As the water stood at this position, a fringing terrace was formed, such as we find at the present time co-extensive with the coast line of the tide water region. Just as in the case of the terrace forming today, this early Pleistocene terrace shelves off toward the main channels, and, by a slight depression seaward relative to the main land farther westward, the top of this terrace also slopes a few feet in the mile eastward. Its old surface has been extensively eroded over considerable areas, and its level character is less apparent than in the case of the later and the lower-lying Wicomico and Talbot.

The deposits consist of clay, sand, and gravel, with here and there ice-borne blocks that have been brought down the rivers by the streams from the mountains to the westward. The materials are for the most part poorly sorted although commonly the coarser sands and gravels are found in the lower part of the formation and the loams in the upper part. The beds seldom have a thickness exceeding 40 feet. A few leaves of recent types have been found in the Sunderland deposits in Maryland but none are reported from Virginia.

The Wicomico Formation.

The Wicomico formation, so called from the river of that name which enters the Potomac from the Maryland bank between Charles and St. Mary's counties, wraps about the Sunderland formation as a terrace at a lower level and from its less elevation and younger age has suffered less from erosion than has the Sunderland. It is found throughout the same general district as is the Sunderland but extends farther seaward, often occurring as a broad plain with a slight slope which stretches from the Sunderland border eastward.

The materials of the Wicomico are very similar to those of the Sunderland, and consist of clays, loams, sands, and gravels, with

here and there beds of peat and scattered ice-borne boulders. A bed of loam commonly forms the top of the formation with sand and gravels below, although the materials in general are poorly sorted. The sands are often cross-bedded, and occur in irregular lenses. The beds seldom exceed 40 feet in thickness and are commonly much less. Clay deposits containing leaf impressions of recent types are not unusual, but no animal remains have as yet been recognized.

The Talbot Formation.

The Talbot formation receives its name from Talbot County, Maryland, which is widely mantled with deposits of this age. In the same manner as the Wicomico formation wraps about the Sunderland so does the Talbot wrap about the Wicomico throughout the Coastal Plain. Its surface has an elevation landward of about 40 feet but this declines slowly seaward, until it falls nearly to sea level. Its level surface can be seen at this elevation throughout the eastern portions of the Coastal Plain on both sides of the Chesapeake Bay. On account of its slight elevation and late origin it has suffered much less from erosion than has any other formation of the Coastal Plain series.

The deposits consist of clays, loams, sands, and gravels, with many peat beds, and here and there ice-borne boulders. The physical and lithological characters are similar to the other formations of Pleistocene age, although at times the gravels seem less decayed than at the older horizons. This is, however, by no means universal. The deposits seldom exceed 30 feet in thickness.

The fossils found in the Talbot formation consist chiefly of leaf impressions, molluscan shells, and at some points of mammalian bones. The mollusca are chiefly marine and a number of localities are known in the Chesapeake Bay district where they occur in large numbers.

The Sunderland, Wicomico, and Talbot formations combined, constitute the Columbia group and possess many characters in common. The materials of which they are made come largely from the earlier Coastal Plain formations, although the streams flowing from the Piedmont and Appalachian districts have brought down additional supplies.

Recent.

The Recent deposits embrace chiefly those which are being laid down today over the submarine portion of the Coastal Plain and along the various estuaries and streams. To these must also be added such terrestrial deposits as talus, wind-blown sand, and humus. In short, all deposits which are being formed today under water or on the land by natural agencies belong to this division of geological time.

The Recent terrace now under construction along the present ocean shore line and in the bays and estuaries is the most significant of these deposits and is the last of the terrace formations which began with the Lafayette, the remnants of which today occupy the highest levels of the Coastal Plain, and which has been followed in turn by the Sunderland, Wicomico, and Talbot.

Beaches, bars, spits, and other formations are built up on this terrace belt and are constantly changing their form and position with the variations in currents and winds. Along the streams flood-plains are formed that in the varying heights of the water suffer changes more or less marked. On the land the higher slopes are often covered with debris produced by the action of frost and the heavy downpours of rain which form at times accumulations of large proportions known as talus and alluvial fans.

A deposit of almost universal distribution in this climate is humus or vegetable mold, which, being mixed with the loosened surface of the underlying rocks, forms our agricultural soils. The ultimate relationship therefore of the soils to the underlying geological formations is evident.

The deposit of wind-blown sands, more or less apparent everywhere, as may be readily demonstrated at every period of high winds, is especially marked along the sea coast, particularly in the vicinity of Cape Henry where sand dunes of large dimensions have been formed. Other accumulations in water and on the land are going on all the time and with those already described represent the formations of Recent time.

Part II

The Clays of the Virginia Coastal Plain

By HEINRICH RIES

CHAPTER II.

THE ORIGIN, PROPERTIES AND MODE OF OCCURRENCE OF CLAYS.

INTRODUCTORY.—Clay is one of the most curious and least understood of our common mineral products, and various investigators have spent much time in attempts to discover the causes of its peculiar properties. In some cases they have partially succeeded; in others it must be admitted that while they have partly solved the problem, they are nevertheless still very far from a complete and satisfactory interpretation of the phenomena discussed.

In the pages here devoted to a discussion of the properties of clay, nothing further is attempted than a description of these characters and their practical value. The scientific discussion of them will be left for the final report which will cover the entire state.

Man at a very early period in the earth's history discovered the peculiar qualities of the common substance known as clay. That its usefulness has steadily increased is evidenced by the fact that in 1904, the value of clay products made in the United States alone exceeded $130,000,000; which was greater than the value of other important products such as gold, silver, copper and petroleum, and was only outranked by iron and coal. This being the case, we can justly regard clay as one of our most important mineral resources, although up to a few years ago it was quite neglected by both government and state surveys.

CLAY DEFINED.—The term clay is applied to a group of earthy materials occurring in nature, whose most prominent character is that of plasticity when wet. This peculiar property permits their being shaped into any desired form when moist, which shape they retain when dried. By exposing the clay to the heat of a fire, it becomes hard and rock-like, thus enabling us to render permanent the form given to it when green or soft. These are two important physical properties which make clay of such great value, but there are a number of minor characters which are also of some importance and will be discussed later.

To the unaided eye, clay usually appears so fine-grained that most of its component grains cannot be identified, although some particles of quartz, or small scales of mica are not infrequently recognizable. Microscopic examination, however, reveals the presence of a number of small mineral grains, many of which are under one one-thousandth of an inch in diameter. In addition to these there are particles of organic matter as well as other small bodies of non-crystalline character, which are classed as colloids, and may be of either organic or inorganic origin. The mineral fragments making up the bulk of the clay represent a variety of compounds in all stages of decomposition, but their properties and effects on the clay will be left until a later page.

ORIGIN OF CLAY.

So far as we know clay results primarily from the decomposition of other rocks, and very often from rocks containing an appreciable amount of the mineral feldspar. There are some rocks, however, that contain practically no feldspar which, on weathering, yield a most plastic clay. In all of these clays there is found a variable amount of the mineral kaolinite, which is of secondary origin, *i. e.*, it is derived from other minerals by decomposition. This is termed the *clay base.*

In order to trace the process of clay formation, let us take the case of granite, a rock which is commonly composed of three minerals, namely, quartz, feldspar, and mica. When such a mass of rock is exposed to the weather, minute cracks are formed in it, due to the rock expanding when heated by the sun and contracting when cooled at night; or there may be joint-planes formed by the contraction of the rock as it is cooled from a molten condition. Into these cracks the rain water percolates and, when it freezes in cold weather, it expands, thereby exerting a prying action, which further opens the fissures, or may even wedge off fragments of the stone. Plant roots force their way into these cracks and, as they expand in growth, supplement the action of the frost, thus further aiding in the breaking up of the mass. This process alone, if kept up, may reduce the rock to a mass of small angular fragments.

The rain water, however, acts in another way. It not only carries oxygen into the pores of the rock, but also acids in solution, the latter being gathered in part from the air, and in part from decaying vegetable matter. The result of this is that the oxygen and the acids attack many of the mineral grains of the rock and change them into other compounds. Some of these are soluble and can be carried off by the water circulating through the mass, but others are insoluble and are left behind. It will thus be seen that one effect of this action is to withdraw certain elements from the rock, and, the structure of the minerals as well as the rock being destroyed, it crumbles to a clayey mass.

The three minerals mentioned as being commonly present in granite are not equally affected, however, by the weathering agents. Thus the quartz grains are but slightly attacked by the soil waters, while the feldspar loses its lustre and changes slowly to a white, powdery mass, which is usually composed entirely of grains of kaolinite. The mica, if whitish in color, remains unattacked for a long time, and the glistening scales of it are often visible in many clays. If the mica is dark colored, due to iron in its composition, it rusts rapidly and the iron oxide, thus set free, may permeate the entire mass of clay and color it brilliantly. The kaolin deposits of Henry county, Virginia, contain much coarse mica, while the surrounding clay is brilliantly colored by iron-oxide liberated in the weathering of iron-bearing mica.

If now a granite, which is composed chiefly of feldspar, decays under weathering action, the rock will be converted into a clayey mass, with quartz and mica scattered through it. Remembering that the weathering began at the surface and has been going on there for a longer period than in deeper portions of the rock, we should expect to find on digging downward from the surface, (*a*) a layer of fully formed clay; (*b*) below this a poorly defined zone containing clay and some partially decomposed rock fragments; (*c*) a third zone, with some clay and many rock fragments; and *(d)* below this the nearly solid rock. In other words there is a gradual transition from the fully formed clay at the surface into the parent rock beneath (Fig. 1). A marked exception to this is found in clays formed from limestone, where the passage from clay to rock is sudden. The reason for this is that the change

3

from limestone into clay does not take place in the same manner as granite. Limestone consists commonly of carbonate of lime, with a variable quantity of clay impurities, so that when the weathering agents attack the rock, the carbonate of lime is dissolved out by the surface waters, and the insoluble clay impurities are left behind as a mantle on the undissolved rock — the change from the rock to clay being, therefore, a sudden one, and not due to a gradual breaking down of the minerals in the rock, as in the case of granite.

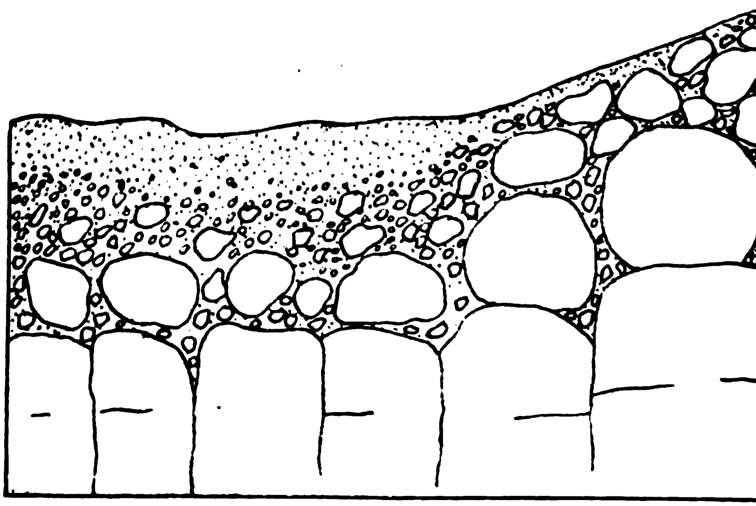

FIG. 1. Section showing passage from residual clay on surface to parent rock below. The clay is thinner on the slopes than in the depressions.

RESIDUAL CLAY.—Where the clay is thus found overlying the rock from which it was formed, it is termed *residual clay,* because it represents the residue of rock decay in place, and its grains are more or less insoluble.

A residual clay formed from a rock containing little or no iron oxide is usually white, and is termed *kaolin,* and deposits of this type generally contain a high percentage of the mineral *kaolinite.* On the other hand, a residual clay derived from a rock containing much iron oxide will be yellow, red, or brown, depending on the iron compounds present. Between the pure white

clays and the brilliantly colored ones, others are found representing all intermediate stages, so that residual clays vary widely in their purity.

The form of a residual clay deposit, which is also variable, depends on the shape of the parent rock. Where the residual clay has been derived from a great mass of granite or other clay-yielding rock, the deposit may form a mantle covering a considerable area. On the other hand, some rocks, such as pegmatites (feldspar and quartz), occur in veins, that is, in masses having but small width as compared with their length, and in this case the outcrop of residual clay along the surface will form a narrow belt. The Henry county kaolin deposits are of this type.

The depth of a deposit of residual clay will depend on climatic conditions, character of the parent rock, topography and location. Rock decay proceeds very slowly, and in the case of most rocks the rate of decay is not to be measured in months or years, but rather in centuries. Only a few rocks, such as some shales or other soft rocks, change to clay in an easily measurable time. With other things equal, rock decay proceeds more rapidly in a moist climate, and consequently it is in such regions that the greatest thickness of residual materials is to be looked for. The thickness might also be affected by the character of the parent rock, whether composed of easily weathering minerals or not. Where the slope is gentle or the surface flat, much of the residual clay will remain after being formed, but on steep slopes it will soon wash away.

In some cases the residual materials are washed away but a short distance and accumulate on a flat or very gentle slope at the foot of the steeper one, forming a deposit not greatly different from the original one, although they are not, strictly speaking, residual clays.

Residual clays, usually of impure character, are widely distributed over the southern portion of the United States, except in the Coastal Plain belt. In Virginia they are to be seen at many points throughout the Piedmont and Appalachian belts where the slopes are not too steep. Around Richmond and Petersburg, for example, the residual clay forms a mantle of variable thickness in the granite quarries, and in the regions underlain by schist

and shale (both easily decomposable rocks), it frequently occurs in masses of great thickness.

Residual clays are commonly highly colored by a large percentage of iron oxide, but in a few instances where they have been derived from a rock poor in iron-bearing minerals, the clay is light yellow or even white.

Uses of Residual Clay.—Owing to their gritty character, caused by the presence of numerous quartz fragments and impure nature, the majority of residual clays cannot be used for anything except common brick. There are, however, occasional deposits which, on account of their fine grain, are available for pottery manufacture; or others which are low in impurities, and can hence be used for making fire brick or even buff pressed brick.

The distribution of Virginia occurrences is left for a future report.

SEDIMENTARY CLAYS.—As mentioned above, residual clays rarely remain on steep slopes, but are washed away by rain storms into streams and carried off by these to lower and sometimes distant areas. By this means residual clays possibly of very different character may be washed down into the same stream and become mixed together. This process of wash and transportation can be seen in any abandoned clay bank, where the clay on the slopes is washed down and spread out over the bottom of the pit.

As long as the stream maintains its velocity it will carry the clay in suspension, but if its velocity be checked, so that the water becomes quiet and free from currents, the particles begin to settle on the bottom, forming a clay layer of variable extent and thickness. This may be added to from time to time, and to such a deposit the name of *sedimentary* clay is applied. All sedimentary clays are stratified or made up of layers, this being due to the fact that one layer of sediment is laid down on top of another.

The stratified character of the clay is not seen with equal clearness in all beds, and to the untrained eye may not always be apparent, but the sand grains and pebbles found in sedimentary clays are always more or less rounded, caused by a rubbing together of the particles while being transported. Plate II, Fig 2, shows a sedimentary deposit of loamy clay overlain by gravel.

Sedimentary clays can be distinguished from residual clays chiefly by their stratification, and also by the fact that they commonly bear no direct relation to the underlying rock on which they may rest.

All sedimentary clays resemble each other in being stratified, but aside from this they may show marked irregularities in structure. (Fig. 2.)

Thus, any one bed, if followed from point to point, may show variations in thickness, pinching or narrowing in one place and thickening or swelling in others.

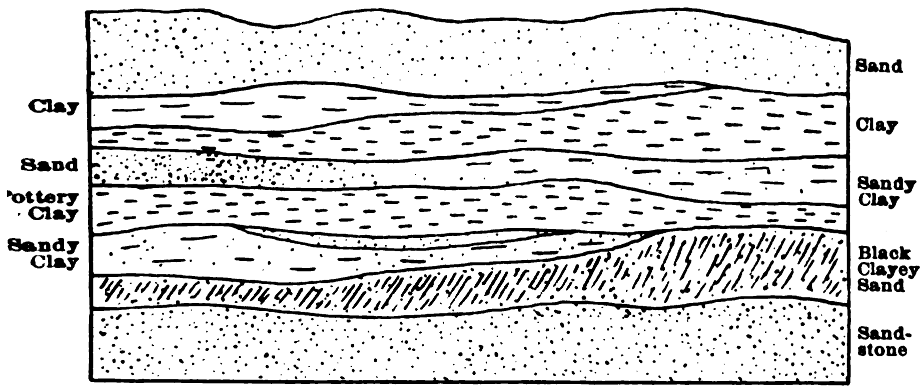

FIG. 2. Section showing how sedimentary clay beds may vary horizontally and vertically.

In digging clay the miner often finds streaks of sand extending through the deposit and cutting through several different layers, these having been caused by the filling of channels cut in the clay deposits by streams. Occasionally a bed of clay may be extensively worn away or corraded by currents subsequent to its deposition, leaving its upper surface very uneven, and on this an entirely different kind of material may be deposited, covering the earlier bed, and filling the depressions in its surface. If the erosion has been deep, adjoining pits dug at the same level may find clay in one case and sand in the other.

While in many instances the changes in the deposit are clearly visible to the naked eye, variations may also occur, due to the same cause, which would only show on burning.

The clays found south of Richmond, Sturgeon Point, Bermuda Hundred, City Point, etc., are in the same formation, and superficially they appear to be very similar; yet in burning they behave somewhat differently as to shrinkage, color, vitrifying qualities, etc. This is due to variations in both their chemical composition and physical character.

All the clays found in the Coastal Plain or Tidewater Belt of Virginia are of sedimentary origin. Those found in other parts of the State are either residual or sedimentary. The former are more abundant, but the latter are the ones more often worked.

As the finer material can only be deposited in quiet water and coarse material in disturbed waters, so from the character of the deposit we can read much regarding the conditions under which it was formed. If, therefore, in the same bank alternating layers of sand, clay and gravel are found, it indicates a change from disturbed to quiet water, and still later rapid currents over the spot in which these materials were deposited. The commonest evidence of current deposition is seen in the cross-bedded structure of some sand beds, where the layers dip in many different directions, due to shifting currents, which have deposited the sand in inclined layers (Pl. II, Fig. 1).

Such conditions as these are by no means uncommon in the Virginia Coastal Plain belt.

Classification of Sedimentary Clays.— Sedimentary clays are deposited under a variety of conditions which tend to influence not only the form of the deposit but in many cases its physical character. The different groups may be briefly referred to as follows:

1. **Marine Clays,** which include all those sedimentary clays deposited on the ocean bottom, where the water is quiet. They have therefore been laid down at some distance from the shore, since nearer the land, where the water is shallower and disturbed only coarse materials can be deposited. This means that in a formation carrying marine clays, the clays may pass into the beds of sand as we go towards the ancient shoreline of the sea in which they were laid down.

Beds of marine clay may be of vast extent and great thickness, but will naturally show much variation, horizontally at

least, because the different rivers flowing into the sea usually bring down different classes of material.

Thus, one stream may carry the wash from an area of iron-stained clay, and another the drainage from an area of white or light-colored clay. As the sediment spreads out over the bottom the areas of deposition might overlap, and there would thus be formed an intermediate zone made up of a mixture of the two sediments. This would show itself later as a horizontal transition from one kind of clay to another. These changes may occur gradually or at other times within the distance of a few feet.

2. **Estuarine Clays** represent bodies of clay laid down in shallow arms of the sea, and are consequently found in areas that are comparatively long and narrow with the deposits showing a tendency towards basin shapes. Estuarine clays often show sandy laminations, and are not infrequently associated with shore marshes. Deposits of this type are found in the coastal belt.

3. **Swamp and Lake Clays** constitute a third class of deposits, which have been formed in basin-shaped depressions occupied by lakes or swamps. They represent a common type of variable extent and thicknesss, but all agree in being more or less basin-shaped. They not infrequently show alternating beds of clay and sand, the latter in such thin laminae as to be readily overlooked, but causing the clay layers to split apart easily.

Clay beds of this type are not especially common in the Coastal Plain of Virginia, but in the areas to the west, are to be looked for in many depressions which have received the wash from the residual clays on the surrounding slopes. Their quality is variable.

4. **Flood-Plain and Terrace Clays.**— Many rivers, especially in broad valleys, are bordered by a terrace or plain, there being sometimes two or more, extending like a series of shelves or steps up the valley side. The lowest of these is often covered by the river during periods of high water, and is consequently termed the flood-plain. In such times much clayey sediment is added to the surface of the flood terrace, and thus a flood-plain clay deposit may be built up.

Owing to the fact that there is usually some current setting along over the plain when it is overflowed, the finest sediments can not settle down, except in protected spots, and, consequently,

most terrace clays are rather sandy, with here and there pockets of fine, plastic clay. They also frequently contain more or less organic matter. Along its inner edge the terrace may be covered by a mixture of clay, sand and stones, washed down from neighboring slopes.

Where several terraces are found, it indicates that the stream was formerly at the higher levels, and has cut down its bed, each terrace representing a former flood-plain. Even along the same stream, however, the clays of the several terraces may vary widely in their character, those of one terrace being perhaps suitable for pottery, and those of a second being available only for common brick and tile.

Flood-plain clays may occur in the Coastal Plain but they are of little importance. They will be found, however, at many points in the Piedmont and Appalachian belts, and are sometimes worked for common brick at least.

5. **Drift or Boulder Clays** are tough, dense, gritty clays, often containing many stones, and represent ice transported material which has been largely ground to fine rock flour, through which are scattered pebbles and boulders. Such deposits are found only in those portions of the United States which were covered by the ice sheet during the glacial period. Glacial clays are, therefore, not found in Virginia. Some of the clays in the Manchester brick-yards (Pl. X, Fig. 2.) contains large boulders but these have probably been dropped in the clay by masses of floating ice.

SECONDARY CHANGES IN CLAY DEPOSITS.

Changes often take place in clays subsequent to their deposition. These may be local or widespread, and in many cases they may either greatly improve the clay or else render it worthless. At a number of localities the entire deposit may have been altered so that it is difficult to tell what its original character was, but in others only a portion of the deposit has been altered, and one can easily trace the changes that have gone on.

The changes which take place in clay subsequent to its formation are of two kinds, namely, mechanical and chemical.

MECHANICAL CHANGES.

FOLDING, TILTING AND FAULTING.—From what has been said regarding the origin of sedimentary clays, it has been seen that they were laid down under water, but the fact that they now appear at the surface indicates that the water has been drained off, either by the water level falling or the sea bottom being elevated. If the latter occurred, and such has been the case in Eastern Virginia, there was little likelihood that the elevation of all points over such a large area was the same, and such a differential uplift has produced a tilting or dipping of the beds towards the southeast.

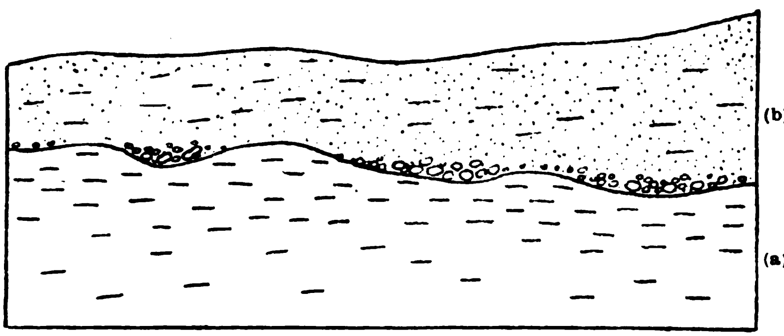

FIG. 3. Section showing clay bed (a), with uneven upper surface caused by erosion. The currents causing this deposited the pebbles in the hollows, and these were in turn covered by a bed of sandy clay (b).

Beds of clay and shale sometimes show folds or undulations. In the Coastal Plain clays of Virginia these are rarely seen, but in the shales of the Appalachian region they are by no means uncommon.

Where beds of clay or shale are bent into arches (anticlinal folds) (Fig. 7) and troughs (synclinal folds), (Fig. 8), each bed slopes or dips away from the axis of an anticlinal fold and towards the axis of a synclinal fold, but if followed parallel to the axis it will remain at the same level, provided the axis itself is horizontal. These considerations are of importance in prospecting for clays in central and western Virginia but they do not have to be considered in the Coastal Plain region.

Where a bed is not sufficiently elastic to bend under pressure, it breaks, and if, at the same time, the beds on the opposite side

of the break slip past each other, this displacement is termed *faulting.* When the breaking surface or fault plane is at a low angle, one portion of the bed may be thrust over the other for some distance. In other cases the displacement may amount to but a few inches. Faulting is not uncommon in some of the shale deposits of central and western Virginia but no evidence of it was observed in the Coastal Plain deposits.

Both tilting and folding exert an important influence on the form and extent of the outcropping beds. Where no tilting has occurred, that is, where the beds are flat, only one bed, the upper one of the section, will be exposed at the surface. Where the latter is level, these lower beds will be exposed only where stream valleys have been carved. (Fig. 5.)

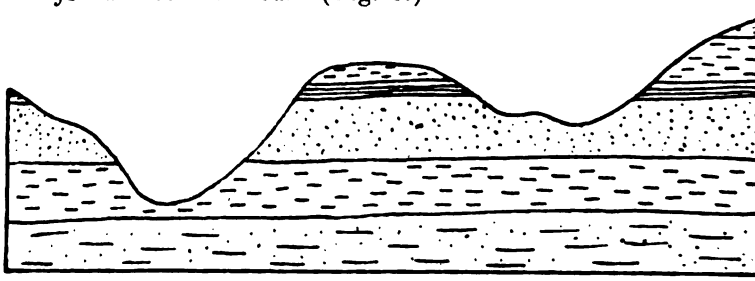

FIG. 4. Section in horizontally stratified beds of clay and sand. The lower beds are exposed in the deeper valleys.

If the beds are tilted or folded and the crest of the folds worn off, then the different beds will outcrop on the surface as parallel bands (Figs. 5 and 6), whose width of outcrop will decrease, with an increase in the amount of dip.

These facts are again especially applicable to the shaly clays of the Great Valley and Allegheny belt.

EROSION.—All land areas are being constantly attacked by the weathering agents (frost, rain, etc.), resulting in a crumbling of the surface rocks and the removal of loose fragments and grains. This brings about a general sculpturing of the surface, forming hills and valleys, the former representing those parts of the rock formations which have not yet been worn away. The effect of this is to cause conditions, which may at first sight appear puzzling, but are nevertheless quite simple, when the cause of them is understood.

If the beds have a uniform dip, the conditions may be as indicated in Fig. 9. Here, bed 1 appears at the summit of two hills, *a* and *b*, but its rise carries it, if extended, above the summit of hill *c*, which is capped by bed 3. If one did not know that the beds

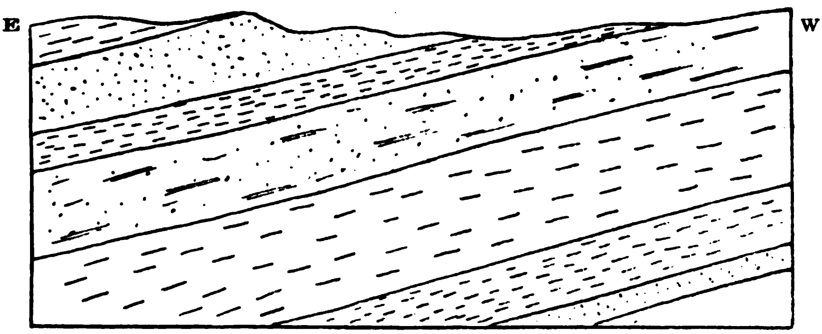

FIG. 5. East-west section showing outcropping beds of inclined strata.

rose in that direction it might be assumed that bed 1 passed into bed 3, because they are at the same level. This dipping of the layers or beds sometimes accounts for the great dissimilarity of beds at the same level in adjoining pits.

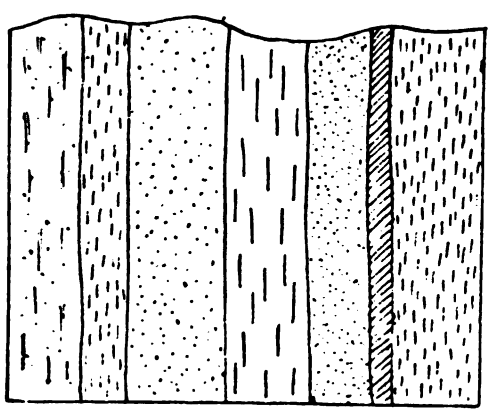

FIG. 6. Section of vertical beds.

Where a bed of clay is found outcropping at the same level on two sides of a hill, it is reasonable to assume that it probably extends from one side to the other, but it is not safe to predict with

certainty, for, as has been mentioned above, clay beds may thin out within a short distance.

It is not always possible to correlate clays by means of their position, and assume that in a region of but slightly tilted strata all those occurring at the same level are of the same age or *vice versa*.

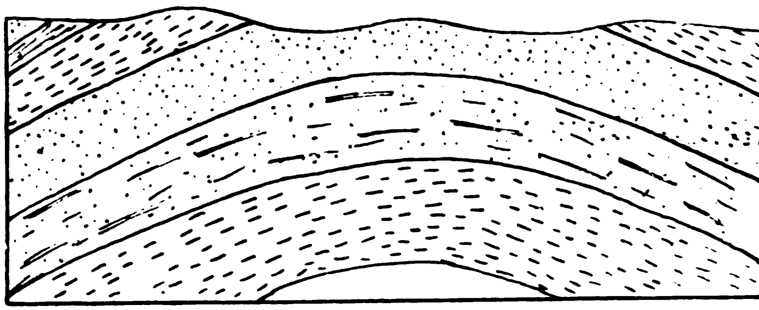

FIG. 7. Section of folded beds. The crest of the arch has been worn away, thus exposing several of the beds.

For example, let us consider a case like that shown in Fig. 1. Here we have a series of horizontally stratified clay and sand beds which have been eroded, but in some places the valleys which

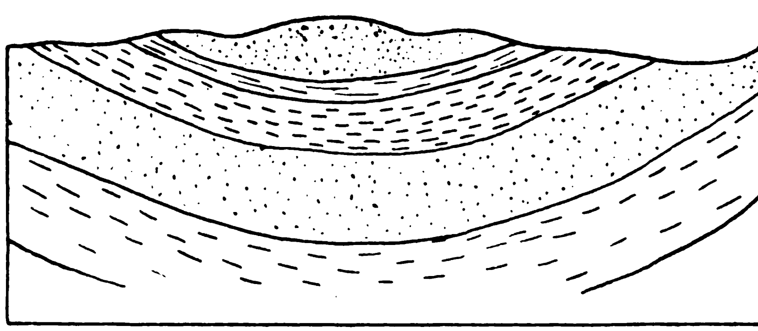

FIG. 8. Section of beds folded into a trough or syncline.

have been cut are much deeper than others. Now if this area were depressed so that the sea could fill the valleys and deposit a series of estuarine clays, these, although formed at the same time, would not be found at the same level after the sea receded. This is not an uncommon phenomenon in the Coastal

Plain region and makes it difficult to formulate a rule for prospecting clays belonging to any given formation. That is to say, if the clays of any one period were deposited at the same level, and had a uniform dip, we could map the line of outcrop and point out the elevation above sea level at which the beds were to be sought for in any given area, but since the clays were not always deposited on a plain surface, this cannot be done.

CHEMICAL CHANGES.

Nearly all clay deposits are affected, superficially at least, by the weather. The changes are chiefly chemical, and can be grouped under the following heads:

Change of color.
Leaching.
Softening.
Consolidation.

CHANGE OF COLOR.—Most clay outcrops which have been exposed to the weather for some time show various tints of yellow

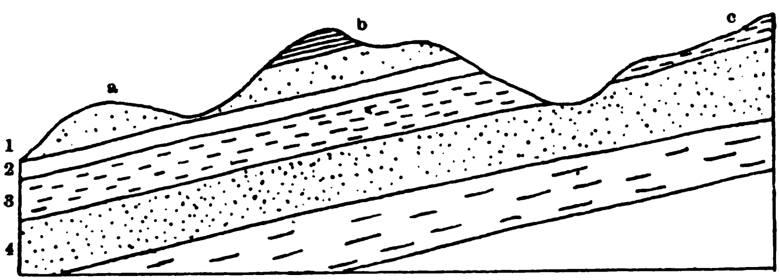

FIG. 9. Inclined beds, showing how they are found at continually higher levels if followed up their slope or dip.

or brown, such discoloration being due to the oxidation or rusting of the iron oxide which the clay contains. This iron compound is usually found in the clay as an original constituent of some mineral and rusts out as the result of weathering, so that the depth to which the weathering has penetrated the material can often be told by the color. The lower limit of this is commonly not only irregular, but the distance to which it extends from the surface depends on the character of the deposits, sandy open clays being affected to a greater depth than

dense ones. The discoloration of a clay due to weathering does not always originate within the material itself, for in many instances, especially where the clay is open and porous, the water seeping into the clay may bring in the iron oxide from another layer, and distribute it irregularly through the lower clay.

The changes of color noticed in clay are not in every case to be taken as evidence of weathering, for in many instances the difference in color is due to differences in mineral composition. Many clays are colored black at one point by carbonaceous matter, whereas a short distance off the same bed may be white or light gray, due to a smaller quantity of carbonaceous material.

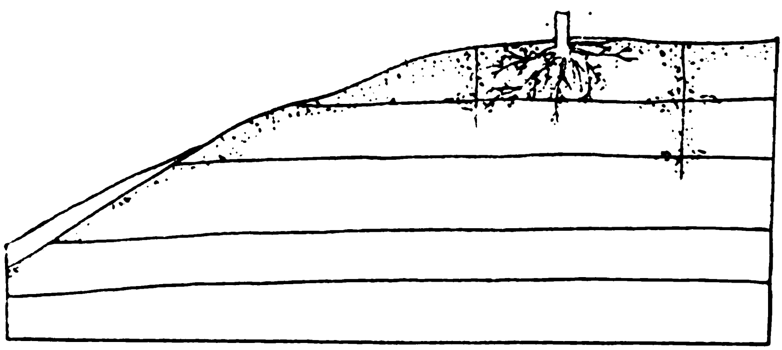

FIG. 10. Section illustrating how weathering penetrates a clay, working in deepest along joint planes, or roots.

Changes in color due to weathering can be distinguished from differences in color of a primary character by the fact that discoloration caused by weathering begins at the surface and works its way into the clay, penetrating to a greater distance along planes of stratification or fissures, and even following plant roots as shown in Fig. 10.

Where the clay deposit outcrops on the top and side of a hill, it does not follow that because the whole cliff face is discolored, the weather will have penetrated to this level from the surface, but indicates simply that the weathering is working inward from all exposed surfaces. The overburden often plays an important role in the weathering of clay, for the greater its thickness, the less will the clay under it be affected. This fact is one which the clay worker probably overlooks, and, therefore, does not appreciate the important bearing which it may have on the behavior of his

material. Some unweathered clays crack badly in drying or burning, but weathering seems to mellow them, as well as to increase their plasticity, so that the tendency to crack is sometimes either diminished or destroyed. If a clay which is being worked shows this tendency it will be advisable to search for some part of the deposit which is weathered, and if the clay is covered by a variable thickness of overburden, the most weathered part will be found usually under the thinnest stripping.

LEACHING.—More or less surface water seeps into all clays and in some cases drains off at lower levels. Such waters contain small quantities of carbonic acid which readily dissolves some minerals, most prominent among them carbonate of lime. In some areas, therefore, where calcareous clays occur, it is not uncommon to find the upper layers of the deposit containing less lime carbonate than the lower ones, due to the solvent action of the percolating waters. This leaching action is especially noticeable in the case of residual clays formed from limestone or calcareous shales, where, during the decomposition or mellowing of the rock under weathering influences, the easily soluble carbonate of lime is removed by percolating waters, so that little or none is found in the residual clay. This is well shown by the two following analyses in which I represents the fresh limestone and II the residual clay derived from it.

	I	II
Silica (SiO_2)	4.13	33.69
Alumina (Al_2O_3)	4.19	30.30
Ferric oxide(Fe_2O_3)	2.35	1.99
Lime (CaO)	44.79	3.91
Magnesia (MgO)	.30	.26
Potash (K_2O)	.35	.96
Soda (Na_2O)	.16	.61
Water (H_2O)	2.26	10.76
Carbonic acid (CO_2)	34.10	0.00
Phosphoric acid (P_2O_5)	3.04	2.54
Manganous oxide (MnO)	4.33	14.98
	100.00	100.00

It is not to be understood that because the particular clay which this analysis represents the composition of runs high in manganese oxide, that all residual clays do.

SOFTENING.—Most weathering processes break up the clay deposits, either by disintegration or by leaching out some soluble

constituents that served as a binding or cementing material, thus mellowing the outcrop, and many manufacturers recognize the beneficial effect which weathering has on their clay. They consequently sometimes spread it on the ground after it is mined and allow it to slake for several months or in some cases several years. The effect of this is to disintegrate thoroughly the clay, render it more plastic, and break up many injurious minerals such as pyrite. Although mentioned under chemical changes it will be seen that the process of softening is partly a physical one.

Some of the pressed brick yards near Alexandria store up their clay, partly for this purpose, but partly as a means of blending the different kinds. Common brick manufacturers rarely follow this plan, it being done at but one yard in eastern Virginia.

CONSOLIDATION.—Some clays, and more especially sandy ones, become somewhat consolidated subsequent to their formation. This is commonly caused by a deposition of limonite (hydrous iron oxide) between the clay particles. In the majority of deposits, where such a change has occurred, the deposition of the limonite takes place in those portions of the clay where the water carrying it can enter, as in cracks, or locally porous parts of the mass. Very few instances of this were noticed in the Virginia Coastal Plain clays, but in the sandy beds accompanying them it was not uncommon. In some, as at Oldfield, the limonite has been deposited around plant rootlets, forming small, irregularly cylindrical concretions, from a quarter of an inch to two inches long.

FORMATION OF SHALE.—This is nothing more than a consolidated clay and its formation is properly referred to under this head. Many sedimentary clays, especially those of marine origin, after their formation, are covered up by many hundred feet of other sediments, due to continued deposition on a sinking ocean bottom. It will be easily understood that the weight of this great thickness of overlying sediment will tend to consolidate the clay by pressure, converting it into a firm rock-like mass, termed shale. That the cohesion of the particles is due mostly to pressure alone is evidenced by the fact that grinding the shale and mixing it with water will develop as much plasticity as is found in many surface clays. An additional hardening has, however, taken place

in many shales, due to the deposition of mineral matter around the grains, as a result of which they become more firmly bound together.

In regions where mountain-making processes have been active and folding of the rocks has taken place, heat and pressure have been developed, and the effect of these have sometimes been to transform or metamorphose the shale into slate or even mica-schist (where the metamorphism was intense), both of which are devoid of any plasticity when ground.

While many shales develop high plasticity, others are so gritty and coarse-grained that they possess little value for the manufacture of clay products. In Virginia, it is only the Paleozoic shales that, so far as known, possess any economic value. There are shales associated with the Triassic coals near Richmond, but these are so gritty and carbonaceous as to preclude their use for the manufacture of clay products. Some of the partially decomposed schists will also prove of value to the clay-worker.

CHEMICAL PROPERTIES OF CLAY.

The Combination of Elements in Clay.—Many chemical elements are found in the rocks of the earth's crust, yet only a few of them are widespread and important. But, by averaging up the analyses of several hundred rocks from all parts of the world, a fairly accurate estimate can be made of the average quantity of each element present. This has been done by F. W. Clarke, chief chemist of the United States Geological Survey, and the results obtained by him are given in the following table. The name of the element is given first, followed by its symbol in parenthesis, and then the average per cent.

Table showing percentage of elements found in the earth's crust.

Oxygen (O)	47.02	Hydrogen (H)	0.17
Silicon (Si)	28.06	Carbon (C)	0.12
Aluminum (Al)	8.16	Phosphorus (P)	0.09
Iron (Fe)	4.64	Manganese (Mn)	0.07
Calcium (Ca)	3.50	Sulphur (S)	0.07
Magnesium (Mg)	2.62	Barium (Ba)	0.05
Sodium (Na)	2.63	Strontium (Sr)	0.02
Potassium (K)	2.32	Chromium (Cr)	0.01
Titanium (Ti)	0.41		

4

Of those mentioned in the above list, carbon and sulphur are the only ones ever found in the elementary state in clays. The others are usually found in combination with each other. Thus, for example, silicon unites with oxygen to form the compound known as silica, which consists of one atom of silicon and two atoms of oxygen, and which would be designated by the symbol SiO_2. Similarly, two of aluminum will unite with three of oxygen, forming the compound known as alumina and represented by the symbol Al_2O_3; again, iron in similar combination may give either FeO or Fe_2O_3; or CaO (lime) may be formed from calcium and oxygen. Carbon and oxygen form CO_2, known as carbon dioxide or carbonic acid gas. If the latter unites with CaO, we get a compound expressed by the symbol $CaCO_3$, and called lime carbonate; CaO and SiO_2 may unite, giving $CaSiO_3$, which is called a silicate of lime because it is a compound containing calcium, silicon and oxygen.

The elements are divisible into two groups, the one known as acid elements, the other as basic elements or bases. The latter are commonly oxides of the metallic elements, and include CaO (lime), MgO (magnesia), Al_2O_3 (alumina), Fe_2O_3 (ferric oxide), K_2O (potash), Na_2O (soda). The acids and bases are strongly opposed in their characters, and, while there is little or no affinity between members of the same group, those of opposite groups show a marked affinity for each other. An acid, therefore, tends to unite with a base under favorable conditions, these conditions being either the presence of moisture or heat, both of which promote chemical activity and therefore combination. Compounds formed by the union of acid elements and basic elements are termed salts, and the different ones possess a different degree of permanence or destructibility. Thus, some exist only at low temperatures, and are broken up or pass off in gaseous form at a red heat, while others may form only at a temperature of redness or higher.

Clay contains a great many different chemical compounds of more or less definite chemical composition, and often having a definite form. Each of these represents a mineral species, possessing definite physical characters, which could be easily seen if the grains of clay were large enough. The latter is the case, however, with only a few of the scattered, coarse grains, which the material may contain, and, consequently, it is necessary to

use a microscope in order to identify the various mineral particles present in any clay, as even a powerful hand glass cannot ordinarily distinguish them.

MINERALS IN CLAY.

Many different kinds of minerals are found in clay, but few of them are present in large amounts, and only a very small percentage of them are recognizable with the naked eye. Those most commonly found are quartz, feldspar, kaolinite, calcite, gypsum, mica, pyrite, dolomite, iron ores, hornblende, and rutile. Of these, quartz is probably always present, and often very abundant. Kaolinite is doubtless rarely wanting; calcite is common in the very calcareous clays.

Quartz.—This mineral, which chemically is silica, is found in at least small quantities in nearly every clay, whether residual or sedimentary, but the grains are rarely large enough to be seen with the naked eye. They are translucent or transparent, usually of angular form in residual clays, and rounded in sedimentary ones, on account of the rolling they have received while being washed along the river channel to the sea, or dashed about by the waves on the beach previous to their deposition in still deeper water. Quartz may be colorless, but it is often colored superficially red or yellow by iron oxide. It breaks with a glassy, shell-like fracture, and is a very hard mineral, being seven in the scale of hardness. It will, therefore, scratch glass, and is much harder than most of the other minerals commonly found in clay, with the exception of feldspar. Quartz at times forms nodules, which have no crystalline structure and are termed flint, or chert, but these are not found in the Coastal Plain clays. They are not uncommon in some of the residual deposits found in Virginia.

Feldspar.— Feldspar is a mineral of rather complex composition, being a mixture of silica and alumina, with either potash, or with lime and soda, and occurring usually in red, pink or white grains. When fresh and undecomposed, the grains have a bright lustre, and split off with flat surfaces or cleavages. Feldspar is slightly softer than quartz, and while the latter, as already mentioned, scratches glass, the former will not. Feldspar rarely occurs

in such large grains as quartz, and, furthermore, is not as lasting a mineral, being easily attacked by the weather or soil waters, and so decomposed to a whitish clay.

Mica.— This is one of the few minerals in clay that can be easily detected with the naked eye, for it occurs commonly in the form of thin, scaly particles, whose bright shining surface renders them very conspicuous even when small. Very few clays are entirely free from mica even in their washed condition, because the light scaly character of the mineral keeps it in suspension, until it settles in quiet water with the clay particles.

There are several species of mica, all of rather complex composition, but all silicates of alumina with other bases. Two of the commonest species are the white mica or muscovite, and the black mica or biotite. The former is a silicate of alumina and potash, and the latter a silicate of alumina, iron oxide and magnesia. Of these two, the muscovite is the most abundant in clay, because it is not readily attacked by the weathering agents. The biotite, on the other hand, rusts and decomposes much more rapidly on account of the iron oxide which it contains. The effect of mica in burning is mentioned under alkalies.

Iron Ores.— This title includes a series of iron compounds, which are sometimes grouped under the above heading, because they are the same compounds that serve as ores of iron, when found in sufficiently concentrated form to make them workable. The mineral species included under this head are:

Limonite ($2Fe_2O_3.3H_2O$)
Hematite (Fe_2O_3)
Magnetite (Fe_3O_4)
Siderite ($FeCO_3$)

The first is an oxide, with three parts of water (a hydrous oxide), the second and third are oxides, and the fourth is a carbonate.

Limonite has the same composition as iron rust. It occurs in various forms, and is often widely distributed in many clays, its presence being shown by the yellow or brown color of the material. When the clay is uniformly colored, the limonite is evenly distributed through it, sometimes forming a mere film on the surface of the grains; at other times it is collected into small

rusty grains, or again it forms concretionary masses of spherical or irregular shape.

Hematite, the anhydrous oxide of iron, is of red color and may be found in clays, but it sometimes changes readily to limonite on exposure to the air and in the presence of moisture.

Magnetite, the magnetic oxide of iron, forms black magnetic grains, and, while not common, is sometimes found when the material is examined microscopically. Like the hematite, it is liable to change to limonite.

Siderite, the carbonate of iron, may occur in clays in the following forms: (1) As concretionary masses of variable size and shape, often strung out in lines parallel with the stratification of the clay. These are more abundant in shales than in clay, and, if near the surface, the siderite concretions change to limonite on their outer surface. (2) In the form of crystalline grains, scattered through the clay and rarely visible to the naked eye. (3) As a film coating other mineral grains in the clay. This mineral will also change to limonite, if exposed to the weather.

Pyrite.— This is another mineral, which is not uncommon in some clays, and can often be seen by the naked eye. It is sometimes called *iron pyrites* or *sulphur*, and, chemically, it is a sulphide of iron (FeS_2). It has a yellow color and metallic lustre, and occurs in large lumps, in small grains or cubes, or again in flat rosette-like forms.

When exposed to weathering action, pyrite is a rather unstable compound, that is to say, it tends to alter, and it changes from sulphide of iron (FeS_2), to the sulphate of iron ($FeSO_4$), by taking oxygen from the waters filtering into the clay. This also destroys its form, the yellow metallic particles changing to a white powdery mineral, which has a bitter taste and is soluble in water. Clays containing pyrite are not, as a rule, desired by the potters. None of the economically valuable clays examined in the Coastal Plain region were found to contain pyrite, but it will be found in many of the carboniferous shales of western Virginia.

Glauconite.— This mineral, which is sometimes termed greensand, and in bulk, greensand marl, or simply marl (an incorrect

term) is an important constituent of some of the Virginia Coastal Plain clays. Chemically, it is a compound containing silica, potash, iron and water (a hydrous silicate of potash and iron), occurring in the form of greenish sandy grains. Its composition is often somewhat variable and it may contain other ingredients as impurities. Thus a sample from New Jersey analyzed: Silica, 50.70 per cent.; alumina, 8.03 per cent.; iron oxide, 22.50 per cent.; magnesia, 2.16 per cent.; lime, 1.11 per cent.; potash, 5.80 per cent.; soda, 0.75 per cent.; water, 8.95 per cent. It is an easily fusible mineral, and hence a high percentage of it is not desired in clay. None of the clays which are being worked contain it so far as known.

Glauconite clay is dug to some extent along the James river, southeast of City Point, but it is used in fertilizer manufacture and not in clay products.

Kaolinite.— This mineral is a compound of silica, alumina and water (a hydrated silicate of alumina), represented by the formula Al_2O_3, $2SiO_2$, $2H_2O$, which corresponds to a composition of silica (SiO_2), 46.3 per cent.; alumina (Al_2O_3), 39.8 per cent.; water (H_2O), 13.9 per cent. It is rarely found in pure masses, but when isolated is found to be a white, pearly mineral, the crystals forming small hexagonal plates, which are often found to be collected into little bunches that can be separated by grinding. When the mineral *kaolinite* forms large masses, the name *kaolin* is applied to it. It is plastic, and is also highly refractory, fusing at cone 36. (See p. 75 under fusibility.) The amount of kaolinite present in clays varies, some white kaolins containing over 98 per cent. while other sandy impure clays may have less than 20 per cent.

Associated with kaolinite, there have been found one or more species of allied minerals which are all hydrated silicates of alumina. They are known as halloysite, rectorite, newtonite, allophane, etc. Some of these have been found in the form of crystals, and others have not.

Rutile.—The oxide of titanium (TiO_2) rutile is of widespread occurrence in clays, and is usually found on chemical analysis, when proper tests are made. Rutile grains can be seen under the microscope in many fire clays, and the analyses show the presence

A. Cross-bedded clay, sand and gravel. Harbaugh's Pit, Richmond.

B. Deposit of loamy clay overlain by gravel, showing sudden change of character often met with in sedimentary clay and sand deposits.
Brower's Pit, Richmond.

ence of titanium oxide to the extent of nearly two per cent. The presence of this mineral, however, is unfortunately too commonly ignored in the analysis of clay, and yet, as will be shown later, its effect on the fusibility of the clay is such that it should not be neglected, in the higher grades at least. It is possible, however, that some of the titanium found in clay, is present in some other form than rutile, such as leucoxene.

Calcite.—This mineral is composed of carbonate of lime, and, when abundant, is found chiefly in clays of recent geological age, but some shales also contain considerable quantities of it. It can be easily detected, for it dissolves rapidly in weak acids, and effervesces violently upon the application of a drop of muriatic acid or even vinegar. When in grains large enough to be seen with the naked eye, it is found to be a translucent mineral with a tendency to split into rhombohedral fragments, due to the presence in it of several directions of splitting or cleavage. It is also soft enough to be easily scratched with a knife. Few clays contain grains of calcite sufficiently large to be seen with the naked eye, although in some the calcite, as well as some other minerals, may form concretions. The concretions, although lacking a granular or crystalline structure, would nevertheless give the acid test.

Gypsum.—This mineral, the hydrous sulphate of lime, contains lime (CaO, 32.6 per cent.), sulphuric acid (SO_3, 46.6 per cent.), and water (H_2O, 20.9 per cent.). It may occur in clays, even in large lumps. The only locality in the Coastal Plain where it was noted was in some clays near City Point on the James river. Here the gypsum forms nodules scattered through the mass, and the clays have no value either for clay products or as a gypsum proposition.

Gypsum when present in clay, and large enough to be visible without the use of a microscope, forms crystals or plate-like masses. It is much softer than calcite and can be scratched with the finger nail; has a pearly lustre, is transparent; and it does not effervesce with acid or vinegar. When heated to a temperature of 250°C. (482°F.), the gypsum loses its water of combination, and when burned to a still higher temperature, at least a part of the sulphuric acid passes off.

Hornblende and Garnet.—These are both silicate minerals of complex composition, which are probably abundant in many impure

clays, but their grains are rarely larger than microscopic size. Both are easily fusible and weather readily, on account of the iron oxide in them, and, therefore, impart a deep red color to clays formed from rocks in which they are a prominent constituent.

Dolomite.—Dolomite, the double carbonate of lime and magnesia, and also magnesite, the carbonate of magnesia, may both occur in clay. They are soft minerals resembling calcite, and either alone is highly refractory, but, when mixed with other minerals, they exert a fluxing action, although not at so low a temperature as lime.

Judging from the very low percentage of magnesia in the Coastal Plain clays, there is but little dolomite or magnesite in them, indeed most of the magnesia which they contain is probably a constituent of mica.

THE CHEMICAL ANALYSIS OF CLAYS.

There are two methods of quantitatively analyzing clays. One of these is termed the ultimate analysis, the other is known as the rational analysis.

THE ULTIMATE ANALYSIS.—In this method of analysis, which is the one usually employed, the various ingredients of a clay are considered to exist as oxides, although they may really be present in much more complex forms. Thus, for example, calcium carbonate ($CaCO_3$), if it were present, is not expressed as such, but, instead, is considered as broken up into carbon dioxide (CO_2) and lime (CaO), with the percentage of each given separately. The sum of these two percentages would, however, be equal to the amount of lime carbonate present. While the ultimate analysis, therefore, fails to indicate definitely what compounds are present in the clay, still there are many facts to be gained from it.

The ultimate analysis of the clay might be expressed as follows:

	Silica	(SiO_2)
	Alumina	(Al_2O_3)
	Ferric oxide	(Fe_2O_3)
	Ferrous oxide	(FeO)
	Lime	(CaO)
Fluxing Impurities	Magnesia	(MgO)
	Alkalies: Potash	(K_2O)
	Alkalies: Soda	(Na_2O)
	Titanic oxide	(TiO_2)
	Sulphur trioxide	(SO_3)
	Carbon dioxide	(CO_2)
	Water	(H_2O)

In most analyses, the first seven of these and the last one are usually determined. The percentage of carbon dioxide is mostly small, and commonly remains undetermined, except in very calcareous clays. Titanic oxide is rarely looked for, except in fire clays, and even here its presence is frequently neglected. Since the sulphur trioxide, carbon dioxide and water are volatile at a red heat, they are often determined collectively and expressed as "*Loss on Ignition.*" If carbonaceous matter, such as lignite, is present, this also will burn off at redness. To separate these four, special methods are necessary, but they are rarely applied, and, in fact, are not very necessary, except in calcareous clays, or black clays. The loss on ignition in the majority of *dry* clays is chiefly chemically combined water. The ferric oxide, lime, magnesia, potash and soda are termed the fluxing impurities, and their effects are discussed under the head of iron, lime, magnesia, etc., and also under Fusibility.

All clays contain a small but variable amount of moisture in their pores, which can be driven off at 100°C. (212°F.). In order, therefore, to obtain results that can be easily compared, it is desirable to make the analysis on a moisture-free sample, which has been previously dried in a hot-air bath. This is unfortunately not universally done, but all the analyses made for this report have been calculated in this way.

The facts obtainable from the ultimate analysis of a clay are the following:

1. The purity of a clay, showing the proportions of silica, alumina, combined water and fluxing impurities. High-grade clays show a percentage of silica, alumina and water, approaching quite closely to those of kaolinite.

2. The refractoriness of the clay; for, other things being equal, the greater the sum of the fluxing impurities, the more fusible the clay.

3. The color to which the clay burns. This may be judged approximately, for clays with several per cent. or more of ferric oxide will burn red, provided the iron is evenly and finely distributed through the clay, and there is no excess of lime. The above conditions will be affected by a reducing atmosphere in burning, or the presence of sulphur in the fire gases.

4. The quantity of water. Clays with a large amount of chemically combined water sometimes exhibit a tendency to crack in burning, and may also show high shrinkage. If kaolinite is the only mineral present containing chemically combined water, the percentage of the latter will be approximately one-third that of the percentage of alumina, but if the clay contains much limonite or hydrous silica the percentage of chemically combined water may be much higher.

5. Excess of silica. A large excess of silica indicates a sandy clay. If present in the analysis of a fire clay, it indicates low refractoriness.

6. The quantity of organic matter. If this is determined separately, and it is present to the extent of several per cent., it would require slow burning if the clay were dense.

7. The presence of several per cent. of both lime (CaO) and carbon dioxide (CO_2) in the clay indicates that it is quite calcareous.

In the table below are given the analyses of a number of Virginia clays, in order to illustrate the variation in comparison which this class of materials shows. To this is added one calcareous clay from another state, as none of those described in this report run high in lime.

	1	2	3	4	5
Silica (SiO_2)	46.38	57.26	55.33	25.72	41.86
Alumina (Al_2O_3)	39.76	28.97	25.69	5.83	10.70
Ferric oxide (Fe_2O_3)	.79	3.10	9.02	1.74	5 02
Lime (CaO)	.44	.04	.22	1.01	14.33
Magnesia (MgO)	05	.19	.08	.11	2.81
Potash (K_2O)	1.80	1.40	2.57	1.31	2.80
Soda (Na_2O)	.20	.42	.25	.64	
Water (H_2O)	10 26	8 44	6.00	3.55	*8 00
Titanic acid (TiO_2)	.28	.14	.81	.06	....
Carbonic acid (CO_2)	....	....	....	....	14 50

* Includes moisture.

1. Washed Kaolin, Oak Level, Henry Co.
2. Clay from between Stafford and Fredericksburg.
3. Red Clay, Fredericksburg.
4. Clay from South Shore of Rappahannock River, near Layton.
5. A Calcareous Clay.

Rational Analysis.—This method has for its object the determination of the percentage of the different mineral compounds present in the clay, such as quartz, feldspar, kaolinite, etc., and

of titanium oxide to the extent of nearly two per cent. The terial. Most kaolins and other high-grade clays consist chiefly of kaolinite, quartz, and feldspar, the kaolinite forming the finest particles of the mass, while the balance is quartz, feldspar, and perhaps mica. The finest particles are known as the clay substance, which may be looked upon as having the properties of kaolinite. Now, as each of these three compounds of the kaolin—clay substance, quartz, and feldspar—have characteristic properties, the kaolin will vary in its behavior according as one or the other of these constituents predominates or tends to increase.

As to the characters of these three, quartz is nearly infusible, nonplastic, has little shrinkage, and is of low tensile strength; feldspar is easily fusible, and alone has little plasticity; kaolinite is plastic and quite refractory, but shrinks considerably in burning. The mica, if extremely fine, may serve as a flux, and even alone is not refractory. It is less plastic than kaolinite and, when the percentage of it does not exceed 1 or 2 per cent., it can be neglected. Some chemists include mica under clay substance, but it does not seem wise, as it differs somewhat in its properties from kaolinite.

The rational composition of a clay can be determined from an ultimate analysis, but the process of analysis and calculation becomes much more complex. The rational analysis is furthermore useful only in connection with mixtures of high-grade clays, in which the variation of the ingredients can only be within comparatively narrow limits. For ordinary purposes the ultimate analysis is of greater value.

Clays may agree closely in their ultimate analysis, and still differ widely in their rational composition.

MINERAL COMPOUNDS IN CLAY AND THEIR CHEMICAL EFFECTS.

All the constituents of clay influence its behavior in one way or another, their effect being often noticeable when only small amounts are present. Their influence can perhaps be best discussed individually.

SILICA.—This is present in clay in two different forms, namely, uncombined as silica or quartz, and in silicates, of which there

are several. Of these one of the most important is the mineral kaolinite, which is found in all clays and is termed the clay base or clay substance. The other silicates include feldspar, mica, glauconite, hornblende, garnet, etc. These two modes of occurrence of silica, however, are not always distinguished in the ultimate analysis of a clay, but, when this is done, they are commonly designated as "free" and "combined silica," the former referring to all silica except that contained in the kaolinite, which is indicated by the latter term. This is an unfortunate custom, for the silica in silicates is, properly speaking, combined silica, just as much so as that contained in the kaolinite. A better practice is to use the term *sand* to include quartz and silicate minerals, other than kaolinite, and which are not decomposable by sulphuric acid. In the majority of analyses, however, the silica from both groups of minerals is expressed collectively as total silica.

The percentage of both quartz and total silica found in clays varies between wide limits.

In the Virginia clays analyzed for this bulletin the average silica percentage was 68.74 per cent. with a minimum of 51.12 per cent. and a maximum of 85.72 per cent.

With the exception of kaolinite, all of the silica-bearing minerals mentioned above are of rather sandy or silty character, and, therefore, their effect on the plasticity and shrinkage will be similar to that of quartz. In burning the clay, however, the general tendency of all is to affect the shrinkage and also the fusibility of the clay, but their behavior is in the latter respect more individual.

Sand (quartz and silicates) is an important anti-shrinkage agent, which greatly diminishes the air shrinkage, plasticity and tensile strength of the clay, its effect in this respect increasing with the coarseness of the material. Clays containing a high percentage of very finely divided sand (silt) may absorb considerable water in mixing, but show a low shrinkage. The brickmaker recognizes the value of the effects mentioned above and adds sand or loam to his clay, and the potter brings about similar results in his mixture by the use of ground flint.

In considering the effects of sand in the burning of clays, it must be first stated that the quartz and silicates fuse at different

temperatures, and each changes its form but little up to its fusion point. A very sandy clay will, therefore, have a low fire shrinkage as long as none of the sand grains fuse, but when fusion begins, a shrinkage of the mass occurs. We should, therefore, expect a low fire shrinkage to continue to a higher temperature in a clay whose sand grains are refractory.

Of the different minerals to be included under sand, the glauconite is the most easily fusible, followed by hornblende and garnet, mica (if very fine-grained), feldspar and quartz. The glauconite would, therefore, other things being equal, act as an anti-shrinkage agent only at low temperatures. Variation in the size of the grain may affect these results.

IRON OXIDE —SOURCES OF IRON OXIDE IN CLAYS.—Iron oxide is one of the commonest ingredients of clay, and a number of different mineral species may serve as sources of it, the most important of which are grouped below:

Hydrous oxide, limonite; oxides, hematite, magnetite; silicates, biotite, glauconite (greensand), hornblende, garnet; sulphides, pyrite; carbonates, siderite.

In some, such as the oxides, the iron is combined only with oxygen, and is better prepared to enter into the chemical combination with other elements in the clay when fusion begins. In the case of the sulphides and carbonates, on the contrary, the volatile elements, namely, the sulphur of the pyrite and the carbonic acid of the siderite, have to be driven off before the iron contained in them is ready to enter into similar union. In the silicates the iron is chemically combined with silica and several bases, forming mixtures of rather complex composition and all of them of low fusibility, particularly glauconite. Several of these silicates are easily decomposed by the action of the weather, and the iron oxide which they contain combines with water to form limonite.

The range of ferric oxide, as determined from a number of clay analyses, is as follows:

AMOUNT OF FERRIC OXIDE IN CLAYS.

Kind of Clay	Minimum	Maximum	Average
Brick clays	0.126	32.12	5.311
Fire clays	0.01	7.24	1.506
Kaolins	....	6.87	1.29

In the Virginia Coastal Plain clays analyzed, ferric oxide ranged from 1.74 per cent. to 10.70 per cent. with an average of 5.33 per cent.

Effects of Iron Compounds.—Iron is the great coloring agent of both burned and unburned clays. It may also serve as a flux and even affect the absorption and shrinkage of the material.

Coloring Action of Iron in Unburned Clay.—Many clays show a yellow or brown coloration, due to the presence of limonite, and a red coloration, due to hematite. Magnetite is rarely present in sufficient quantity to color the clay; siderite or pyrite may color it gray, and it is probable that the green color of many clays is caused by the presence of silicate of iron. The intensity of color is not always an indication of the amount of iron present, since the same quantity of iron oxide may, for example, color a sandy clay more intensely than a fine-grained one, provided both are nearly free from carbonaceous matter; the latter, if present in sufficient quantity, may even mask the iron coloration completely. The coloring action will, moreover, be effective only when the iron is evenly distributed through a clay in an extremely fine form. It is probable that the limonite, coloring clays, is present in an amorphous or non-crystalline form, and forms a coating on the surface of the grains.

Coloring Action of Iron Oxide in Burned Clay.—All of the iron ores will, in burning, change to the form of oxide, provided the clay is not completely vitrified, and so affect the color of the burned material; if vitrification occurs, the iron oxide enters into the formation of silicates of complex composition. The color and depth of shade produced by the iron will, however, depend on: 1st, the amount of iron in the clay; 2d, the temperature of burning; 3d. condition of the iron oxide; and 4th, the condition of the kiln atmosphere.

1. Clay perfectly free from iron oxide burns white. If a small quantity, say 1 per cent., is present, a slightly yellowish tinge is imparted to the burned material, but an increase in the iron content up to 2 or 3 per cent. produces a buff product, while 4 or 5 per cent. of iron oxide makes the clay burn red.

2. If a clay is heated to successively higher temperatures, it is found that, other things being equal, the color usually deepens

as the temperature rises. Thus, if a clay containing 4 per cent. of iron oxide is burned at a low temperature, it will be pale red, and harder firing will be necessary to develop a good brick red, which will pass into a deep red and then reddish purple.

3. Among the oxides of iron two kinds are recognized, known respectively as the ferrous oxide (FeO) and ferric oxide (Fe_2O_3). In the former we see one part of iron united with one of oxygen, while in the latter one part of iron is combined with one and one-half of oxygen. The ferric oxide, therefore, contains more oxygen per unit of iron than the ferrous salt, and represents a higher stage of oxidation. In the limonite and hematite the iron is in the ferric form, representing a higher stage of oxidization. In magnetite both ferrous and ferric iron are present, but in siderite the ferrous iron alone occurs. In the ultimate chemical analysis the iron is usually determined as ferric oxide, no effort being made to find out the quantity present as carbonate or sulphide.

Iron passes rather readily from the ferric to the ferrous form, and *vice versa.* Thus, if there is a deficit of oxygen in the inside of the kiln the iron does not get enough oxygen and the ferrous compound results, but the latter changes at once to the ferric condition, if sufficient air carrying oxygen is admitted. Similarly, if ferric oxide is present in a clay containing considerable carbonaceous matter, the latter will, if it cannot get enough oxygen from the kiln atmosphere, take it from the ferric oxide and so reduce the latter to the ferrous condition. The same change may be produced by smoky fires. The necessity for recognizing these two forms of iron oxide is because they affect the color of the clay differently. Ferrous oxide alone is said to produce a green color when burned, while ferric oxide alone may give purple or red, and mixtures of the two may produce yellow, cherry red, violet, blue and black. Seger found that combinations of ferric oxide with silica produced a yellow or red color in the burned clay. We may thus get a variation in the color produced in burning clay depending on the character of oxidation of the iron, or by mixtures of the two oxides.

It is found sometimes that bricks after burning show a black core, due to the iron in the centre of the brick being prevented from oxidizing (see Carbon in clay), but this should not be confused with the black coloration seen on the ends of many arch

brick, which is caused by the slagging action of the impurities in the fuel.

4. Since the stage of oxidization of the iron is dependent on the quantity of air it receives during burning, the condition of the kiln atmosphere is of great importance. If there is a deficiency of oxygen in the kiln so that the iron oxide, if present, is reduced to the ferrous condition, the fire is said to be *reducing*. If, on the contrary, there is an excess of oxygen, so that ferric oxide is formed, the fire is said to be *oxidizing*. These various conditions are often used by the manufacturer to produce certain shades or color effects in his ware. Thus, for example, the manufacturer of flashed brick produces the beautiful shading on the surface of his product by having a *reducing* atmosphere in his kiln followed by an *oxidizing* one. The potter aims to reduce the yellow tint in his white ware by cooling the kiln as quickly as possible to prevent the iron from oxidizing.

FLUXING ACTION OF IRON OXIDE.—Iron oxide is a fluxing impurity lowering the fusing point of a clay and this effect will be more pronounced if the iron is in the ferrous state or if silica is present. A low iron content is, therefore, desirable in refractory clays, and the average of a number of analyses of these shows it to be 1.3 per cent. Brick clays which are usually easily fusible, contain from 3 to 7 per cent. of iron oxide.

Effect of Iron Oxide on Absorptive Power and Shrinkage of Clay.—So far as the writer is aware no experiments have been made to discover the increased absorptive power of a clay containing limonite, although the clay soils show that the quantity of water absorbed is greater with limonite present. The greater absorptive power may be accompanied by an increased shrinkage. The fire shrinkage might also be great because of the increased loss of combined water due to the presence of limonite.

LIME.—Lime is found in many clays, and in the low-grade ones may be present in large quantities at times. Quite a large number of minerals may serve as sources of lime in clays, but all fall into one of the three following groups:

1. Carbonates. Calcite, dolomite.
2. Silicates containing lime, such as feldspar, garnet.
3. Sulphates. Gypsum.

When the ultimate analysis of a clay shows several per cent. of lime (CaO), it is usually present as an ingredient of lime carbonate ($CaCO_3$), and in such cases its presence can be easily detected by effervesence if a drop of muriatic acid or vinegar is put on the clay. When present in this form it is apt to be finely divided, although it may occur as concretions or limestone pebbles.

When lime is present as an ingredient of silicate minerals, such as those mentioned above, its presence cannot be detected with muriatic acid. It is doubtful, however, if many calcareous clays contain much lime in this combination and the fact that practically all limy clays, so indicated on chemical analysis, give a strong test with muriatic acid, strengthens this theory. Gypsum, which is found in a few clays, is often of secondary character, having been formed by the action of sulphuric acid on lime-bearing minerals in the clay. Since these three groups of minerals behave somewhat differently, their effects will be discussed separately.

Effect of lime carbonate on clay.— Lime is probably most effective in the form of the carbonate. When clays containing it are burned, they not only lose their chemically combined water, but also their carbon dioxide, but while the water of hydration passes off between 450°C. (842°F.) and 600°C. (1112°F.), the carbon dioxide (CO_2) does not seem to go off until between 600°C. (1112°F.) and 725°C. (1562°F.). In fact, it more probably passes off between 850°C. (1562°F.) and 900°C. (1652°F.). The result of driving off this gas in addition to the chemically combined water is to leave calcareous clays more porous than other clays up to the beginning of fusion.

If the burning is carried only far enough to drive off the carbonic acid gas, the result will be that the quicklime thus formed will absorb moisture from the air and slake. No injury may result from this if the lime is in a finely divided condition, and uniformly distributed through the brick, but if, on the contrary, it is present in the form of lumps, the slaking and accompanying swelling of these may split the ware.

If, however, the temperature is raised higher than is required simply to drive off the carbon dioxide, and if some of the mineral particles soften, a chemical reaction begins between the lime, iron

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and some of the silica and alumina of the clay, the result being the formation within the clay of a new silicate compound of very complex composition. The effects of this combination are several. In the first place, the lime tends to destroy the red coloring of the iron, and impart instead a buff color to the burned clay. This bleaching action—if we may call it such—is most marked when the percentage of lime is three times that of the iron. It should be remembered, however, that all buff-burning clays are not calcareous, and that a clay containing a low percentage of iron oxide may also give a buff body. Another effect of lime, if present in sufficient quantity, is to cause the clay to soften rapidly, thereby sometimes drawing the points of incipient fusion and viscosity within 41.6°C. (76°F.) of each other. This rapid softening of calcareous clays is one of the main objections to their use, and on this account also, it is not usually safe to attempt the manufacture of vitrified products from them, but, as mentioned under magnesia, the presence of several per cent. of the latter substance will counteract this. It has also been found possible to increase the interval between the points of incipient fusion and viscosity by the addition of quartz and feldspar.

Many erroneous statements are found in books, regarding the allowable limit of lime in clays, some writers putting it as low as 3 per cent.; still a good building brick can be made from a clay containing as much as 20 per cent. or 25 per cent. of lime carbonate, provided it is in a finely divided condition and a vitrified ware is not attempted. If, however, that much lime is contained in the clay in the form of pebbles, then much damage may result from bursting of the bricks, when the lumps of burned lime slake, by absorbing moisture from the air.

Clays containing a high percentage of lime carbonate are used in the United States, especially in Michigan, Wisconsin and Illinois, for making common brick, common earthenware, roofing, tile and some terra cotta.

Effect of Lime-bearing Silicates.—The effect of these is much less pronounced than that of lime carbonate. They contain no volatile elements, and hence do not affect the shrinkage as lime carbonate does. They serve as fluxes, but do not cause a rapid softening of the clay.

Effect of Gypsum.—Lime, if present in the form of gypsum, seems to behave differently from lime in the form of carbonate although few clays contain large percentages of it.

Gypsum, as already shown, is a hydrous sulphate of lime. In calcining gypsum for making plaster of Paris, the chemically combined water is driven off at 250°C., and it has probably been usually taken for granted that the sulphuric acid was driven off at a red heat, but only a portion of it volatilizes up to a temperature of 1300°C.

The range of lime, as determined from a series of clays, is as follows:

AMOUNT OF LIME IN CLAYS.

Kind of Clay	Minimum	Maximum	Average
Brick clays	0.024	15.38	1.513
Pottery clays	0.011	9.90	1.098
Fire clays	0.03	15.27	0.655
Koalins	tr.	2.58	0.47

In the Virginia Coastal Plain clays it ranged from 0 per cent. to 1.46 per cent. with an average of 0.45 per cent.

MAGNESIA (MgO) rarely occurs in clay in larger quantities than 1 per cent., and, so far as known, none of the Virginia clays are exceptions to this rule. When present, its source may be any one of several classes of compounds, i. e., silicates, carbonates, or sulphates.

In the majority of clays the silicates, no doubt, form the most important source, and minerals of this type carrying magnesia are the black mica or biotite, hornblende, chlorite, and pyroxene. These are scaly or bladed minerals, of more or less complex composition, and containing from 15 per cent. to 25 per cent. of magnesia. The biotite mica decomposes or rusts very easily, and its chemical combination being thus destroyed, the magnesia is set free in the form of a soluble compound, which may be retained in the pores of the clay. Hornblende is not an uncommon constituent of some clays, especially in those which are highly stained by iron, and which have been derived from dark-colored igneous rocks. Like biotite, it alters rather rapidly on exposure to the weather. Dolomite, the mixed carbonate of lime and magnesia, is no doubt present in some clays, and would then serve as a

source of magnesia. Magnesium sulphate, or Epsom Salts, probably occurs sparingly in clays, and might form a white coating either on the surface of clay spread out to weather, or else on the ware in drying. It is most likely to occur in those clays which contain pyrite, the sulphide of iron (FeS_2), for the decomposition of the latter would yield sulphuric acid, which, by attacking any magnesium carbonate in the clay, might form magnesium sulphate. This substance has a characteristic bitter taste.

The effect of magnesia is quite different from that exerted by the lime, for mixtures containing magnesia do not vitrify suddenly, as in the case of calcareous clays.

The effect of magnesia, therefore, if present in sufficient quantity, is to act as a flux and make the clay soften slowly instead of suddenly, as in the case of calcareous clays.

The range of magnesia in several classes of clays, as figured from a number of analyses, is as follows:

AMOUNT OF MAGNESIA IN CLAYS

Quality	Minimum	Maximum	Average
Brick clays	0.02	7.29	1.052
Pottery clays	0.05	4 80	0.85
Fire clays	0.02	6.25	0.513
Kaolins	tr.	2.42	0.223

In the Virginia Coastal Plain clays it ranged from .05 per cent to 1.18 per cent. with an average of .38 per cent.

ALKALIES.—The alkalies include potash (K_2O), soda (Na_2O), and ammonia (NH_3). There are other alkalies but they are probably of rare occurrence in clays.

The amount of total alkalies contained in a clay varies from a mere trace in some to 7 per cent. or 9 per cent. in others. The range of alkalies in several classes of clays was determined to be as follows:

AMOUNT OF TOTAL ALKALIES IN CLAYS

	Range	Average
Kaolins	0.1 - 6.21	1.01
Fire clays	0.048- 5.27	1.46
Pottery clays	0.52 - 7.11	2.06
Brick clays	0.17 -15.32	2.768

In the Virginia Coastal Plain clays potash ranged from .75 per cent. to 3.13 per cent. with an average of 2.05 per cent.; and soda from .22 per cent. to 1.33 per cent. with an average of .72 per cent.

Ammonia is, no doubt, present in some raw clays, judging from their odor, and it may possibly exert some effect on the physical structure of the clay, it being found that the bunches of grains in a clay tend to separate more easily, when the clay is agitated with water, if a few drops of ammonia are added. As ammonia is easily volatile, it leaves the clay as soon as the latter is warmed, and, therefore, plays no part in the burning of the clay. The two other common alkaline substances, potash and soda, are more stable in their character, and are, therefore, sometimes termed *fixed alkalies.* These have to be reckoned with in burning, for they are present in nearly every clay.

Several common minerals may serve as sources of the alkalies. Feldspar may supply either potash or soda or both. Muscovite, the white mica, contains potash. Greensand or glauconite contains potash. Other minerals, such as hornblende or garnet, might serve as sources of the alkalies, but are unimportant, as they are rarely present in clays in large quantities.

Orthoclase, the potash feldspar, contains 17 per cent. of potash (K_2O), while the lime-soda feldspars contain from 4-12 per cent. of soda (Na_2O), according to the species. The lime-soda feldspars fuse at a lower temperature than the potash ones, but are also less common.

Muscovite mica contains nearly 12 per cent. of potash and may contain a little soda. Muscovite flakes, if heated alone, seem to fuse at cone 12, but, when mixed in clay, they appear to act as a flux at different temperatures, according to the size of the grains. If very finely ground, the mica seems to vitrify at as low a temperature as cone 4, but if the scales are larger, they will retain their individuality up to cone 8, or even 10.

We, therefore, see that the minerals supplying alkalies are all silicates of complex composition. Each has its fixed melting point, and the temperature at which the alkalies flux with the clay will depend on the containing mineral, and also on the size of the grains. If the alkali-bearing mineral grains decompose, the potash or soda is set free and forms soluble compounds.

Alkalies are considered to be the most powerful fluxing material that the clay contains, and, if present in the form of silicates, are a desirable constituent, except in clays of a refractory character. On account of their fluxing properties, they serve, in burning, to bind the particles together in a dense, hard body, and permit a white ware, made of porous-burning clays, to be burned at a lower temperature than it otherwise could. In the manufacture of porcelain, white earthenware, encaustic tiles and other wares made from white-burning clays, and possessing an impervious body, feldspar is an important flux.

Alkalies alone seem to exert little or no coloring influence on the burned clay, although in some instances potash seems to deepen the color of the ferruginous clay in burning.

TITANIUM is an element which is found in several minerals, some of which are more common in clays than is usually imagined, although they appear rare because they are seldom found in large quantities. Among the titanium-bearing minerals, the commonest is *rutile,* which is an oxide of titanium (TiO_2), containing 60 per cent. of metallic titanium and 40 per cent. of oxygen. So far as known it is never found in clays in sufficiently large grains to be visible to the naked eye, although a microscopic examination may often show its presence in the form of little needles or grains. Its frequent occurrence is, no doubt, due to the fact that it is quite resistant to weathering. Leucoxene might also be present.

Very few State Geological Surveys, in investigating their clay resources, have made special determinations of this mineral, but in an investigation of the clays of New Jersey, made in 1877, Prof. Cook found that in 21 clays examined it ranged from 1.06 to 1.93 per cent. In a series of Pennsylvania fire clays the percentage of titanium oxide ranged from 0.87 per cent. to 4.62 per cent.

In the Virginia Coastal Plain clays analyzed, titanium oxide ranged from 0 per cent. to 1.95 per cent. with an average of .44 per cent.

Titanium serves as a flux at high temperatures, and even 1 or 2 per cent. may lower the fusion point of a refractory clay slightly. It is also probable that it may cause some of the yellowish tint seen in some clays which have an exceedingly low percentage of iron. So far as we know a small percentage of it does not materially affect the qualities of the lower grade clays.

WATER.—Under this head are included two kinds of water 1. Mechanically admixed water or moisture. 2. Chemically combined water.

Mechanically admixed water.— The mechanically admixed water is that held in the pores of the clay by capillary action, and filling all the spaces between the clay grains. When these spaces are small the clay may absorb and retain a large quantity, because each interspace acts like a capillary tube. If the spaces exceed a certain size they will no longer hold the moisture by capillary action, and the water, if poured on the clay, would fast drain away. The fine-grained clays and sands, for these reasons, show high power of absorption and retention, while coarse sandy clays or sands represent a condition of minimum absorption. This same phenomenon shows itself in the amount of water required for tempering a clay. It is not the highly aluminous ones, however, that always absorb the most water. The total quantity found in different clays varies greatly. In some air-dried clays it may be as low as 0.5 per cent., while in those freshly taken from the bank it may reach 30 to 40 per cent. without the clay being very soft.

Water held mechanically in a clay will pass off partly by evaporation in air, and it can all be driven off by heating the clay to 100°C. (212°F.). The evaporation of the mechanical water is accompanied by a shrinkage of the mass which ceases, however, when the particles have all come in contact and before all the moisture is driven off, because some remains in the pores of the clay. This last portion is driven off during the early stages of burning, and this part of the burning process is referred to as water-smoking or steaming. The shrinkage that takes place when the mechanical water is driven off varies, ranging from 1 per cent. or less in very sandy clays up to 10 or 12 per cent. in very plastic ones.

Since most clays having a high absorption shrink considerably in drying, there is often danger of their cracking, especially if rapidly dried, owing to the rapid escape of water vapor. Mechanical water may hurt the clay in other ways. Thus, if the material contains any mineral compounds which are soluble in water, the latter, when added to the clay, will dissolve a portion of them at least. During the drying of the brick, the water rises to the surface to evaporate, and brings out the compounds in solution, leaving

them behind when it vaporizes. It may also help the fire gases to act on certain elements of the clay, a point explained under burning. Black coring is indirectly affected by it. (See Carbon.)

Chemically combined water.—Chemically combined water, as its name indicates, is that which exists in the clay in chemical combination with other elements, and which, in most cases, can be driven out only at a temperature ranging from 400°C. (752°F.) to 600°C. (1112°F.). This combined water may be expelled from several minerals such as kaolinite which contains nearly 14 per cent.; white mica or muscovite with 4 to 5.5 per cent.; and limonite with 14.5 per cent. Unless a clay contains considerable limonite or hydrous silica the percentage of combined water is commonly about one-third the percentage of alumina contained in the clay. In pure or nearly pure kaolin there is nearly 14 per cent. Other clays contain varying amounts, ranging from nearly 14 per cent. down to 3 per cent. or 4 per cent., the latter being the quantity found in some very sandy clays. The loss of its combined water is accompanied by a slight, but variable shrinkage in the clay, which reaches its maximum sometime after all the volatile substances have been driven off.

CARBONACEOUS MATTER.—Under this head is included all matter of carbonaceous character, most of which is of vegetable origin. Few sedimentary clays are entirely free from it, the material having become incorporated with the clay during its deposition. Although when first mixed with the clay it may have been more or less fresh it has since often undergone subsequent changes which imparted to it an asphaltic or coaly character.

Carbonaceous material may occur in clay in three different forms, namely:

1. Vegetable tissue, such as wood, leaves, stems, etc., in which form it is but slightly altered, and when of this character it is commonly found in surface clays of recent origin. Organic matter of this character rarely affects the color of the raw clay and it burns out so easily, that it causes but little trouble; then too, it is not present in large quantity, rarely exceeding one per cent.

2. Carbonaceous matter of asphaltic or bituminous character. This burns readily at a low red heat, because of the highly combustible gases given off by it. It is found in some clays and in

many shales, especially in those associated with coal seams, and in the shales which are worked may range anywhere from 0 to 10 per cent. If in excess of 10 per cent. the shales are not workable. Even 5 to 6 per cent. cause much trouble in burning.

3. Hard or coaly carbon, resembling anthracite. This burns slowly, and gives off but few combustible gases.

Effects of carbon in clay.—Only the second and third of the kinds mentioned need to be considered. The first alone causes trouble when it occurs in the form of sticks or thick roots and has to be screened out. It is therefore not included in what follows.

Carbonaceous matter often serves as a strong coloring agent of raw clays. If present in small amounts it tinges them gray or bluish-gray, while larger quantities cause a black coloration. Indeed so strong may this be, that it masks the effect of other coloring agents, such as iron. In fact two clays, colored black, might burn red and white, respectively, because one had much iron and the other none, and yet owing to their black color this could not be foretold with certainty.

Asphaltic carbon, aside from its coloring action, often causes much trouble in burning, causing black cores, or even swelling and fusing of the brick. More than this, it may keep the iron in a ferrous condition and prevent the development of the best color effects in the ware.

This is due to several causes. Carbon has a strong affinity for oxygen, much stronger than that of iron, therefore as long as it remains in the clay it will monopolize the supply of oxygen and keep the iron in a ferrous condition, the form in which much of it is in gray or black clays and shales. In burning a clay one of the aims is to get the iron into the ferric condition, so as to fully develop its coloring property. As long as any carbonaceous matter remains there is little or no chance for the iron to oxidize, and, consequently, the carbon must be burned out.

What the manufacturer needs to do, then, is this: First, water smoke the clay; second, burn the carbon out; and third, oxidize the iron. In order to burn off the carbon and oxidize the iron, air supplying oxygen must be drawn into the kiln during burning, for the gases resulting from the combustion of the fuel will supply none. Moreover, the brick or ware must be sufficiently porous to

permit these oxidizing gases to enter and perform their task, which means that this must be done before the clay enters the period of vitrification and the pores begin to close up, due to a shrinkage and fusion of the mass.

What then is the best temperature at which this can be peformed? The experiments of Orton and Griffin* have shown that from 800°C. and 900°C. is the best temperature interval. Below this the oxidation of the carbon does not proceed as rapidly and above this there is danger of vitrification beginning and the oxidation process being stopped.

The method of procedure would, therefore, be to thoroughly watersmoke the ware, then raise the heat as rapidly as possible to a temperature between 800°C. and 900°C. and hold it there until the black core is entirely gone.

Oxidation may be accelerated by increasing the amount of air entering the kiln and by reducing the density of the clay as much as possible. Fineness of grinding also assists it. In case the oxidation is not complete, and the pores of the clay close up before all the carbon is burned off, the expansion of the gases given off by the carbon will bloat the clay as soon as it becomes soft, and this may even be followed by complete fusion of the mass. When the carbon is all burned off, then the iron has a chance to oxidize.

If the clay contains much asphaltic carbon, then the oxidation must be carried on with as little air as possible, otherwise the heat generated by the burning hydrocarbons may be so intense as to vitrify the ware before the oxidation is completed.

Since dense clays are more difficult to oxidize than porous ones, the process of manufacture may also influence the results, and in this connection it has been found that bricks made by the soft-mud process are most rapidly oxidized, followed by either the stiff mud or dry-press (there being no difference between the two), and lastly by the semi-dry-press.

Black coring in Virginia clays.—The only clays of the series tested from the Coastal Plain, which showed a serious tendency to black core, were those from the Miocene south of Chester. These, if used, would require careful treatment. The blue clays at Suffolk

*Second Report of Committee on Technical Investigation, Indianapolis, 1905.

also require plenty of air in the earlier stages of burning, but little serious trouble is experienced with them.

Effect of water on black coring.— It is often stated by brick makers, that black cores are caused by the brick being set too wet. This is not strictly true, and the relation is but a very indirect one. While carbon burns off most rapidly between the temperature of 800°C. and 900°C., still it also passes off somewhat at much lower temperatures. If now the brick is set wet, it requires so much more heat in the early stages of firing to drive out or evaporate the water, that other changes, such as the oxidation of the carbon, will be retarded, and the brick begins to vitrify before it is all driven out.

PHYSICAL PROPERTIES OF CLAY.

THE PHYSICAL PROPERTIES OF CLAY discussed here are plasticity, tensile strength, shrinkage, fusibility, texture, color, slaking and absorption.

PLASTICITY.—As already stated, this property is peculiarly characteristic of clays, and by virtue of it they can be shaped into any desired form. The cause of it need not be discussed here, but will be left to a future report on the Virginia clays of the Piedmont and Mountain belts.

Clays, as is well known, vary widely in their plasticity, some very sandy ones being of low plasticity or lean, while others are highly plastic or fat. Although scientists have not yet been able to satisfactorily explain the cause of plasticity, the clay-worker finds it possible to alter it to some extent. Thus a very plastic clay can be rendered less so by mixing it with sand, or a lean clay can often have its plasticity increased by washing.

TENSILE STRENGTH.—The tensile strength of a clay is the resistance which it offers to rupture on being pulled apart when air-dried. It is an important property by virtue of which the unburned clay ware is able to withstand shocks and strains of handling and probable shrinkage in drying. Through it, also, the clay is able to carry more or less nonplastic material which may be added to reduce the shrinkage. The tensile strength is not to be regarded as an index to the plasticity. Some clays of high tensile

strength show a high plasticity, but all do not. Others of low tensile strength are often highly plastic to the feel.

The tensile strength is measured by moulding the tempered clay into briquettes of similar form and dimensions to those made for testing cement and, when they are thoroughly air-dried, pulling them apart in a suitable testing machine. The cross section of the briquettes when moulded is 1 square inch and, after being formed, they are allowed to dry first in the air and then in a hot-air bath at a temperature of 100°C. (212°F.). When thus thoroughly dried the briquette is placed in a machine, in which its two ends are held in a pair of brass clips, and is subjected to an increasing tension until it breaks in two. Theoretically, the briquette should break at its smallest cross-section, with a smooth, straight fracture, and when this does not occur it is due either to a flaw in the briquette or because the clips tend to cut into the clay. In such event the briquette breaks across one end. In order to prevent this it is necessary to put some soft material, such as asbestos, pasteboard or rubber between the inner surface of the clip jaws and the sides of the briquette. If the briquettes are moulded and dried with care, the variation in the breaking strength of the individual briquettes should not vary more than 15 or 20 per cent., but with some very plastic clays it is extremely difficult to keep the variation within these limits.

In testing the Virginia clays 12 briquettes were made of each sample, and the average of these taken. In case a briquette broke very low on account of a flaw, it was not averaged in.

The tensile strength of clay briquettes is expressed in pounds per square inch, but, since the briquettes shrink in drying, the strength actually obtained will be less than that for one square inch, and the result must be increased in proportion to the amount the briquette has shrunk.

Practically all kinds of clay, excepting kaolins, show great variation in their tensile strength. The latter are always of low strength, but the former may be either low or high. In the Virginia Coastal Plain clays tested the tensile strength ranged from 34 pounds to 300 pounds per square inch.

SHRINKAGE.—All clays shrink in drying and burning, the former loss being termed the air shrinkage, and the latter the fire shrinkage.

Air shrinkage.—When a mass of clay is mixed with water, each of the grains of clay can be considered as being surrounded by a film of liquid, which may prevent the grains from coming into close or actual contact. As soon as the wet, moulded mass is set aside to dry, however, evaporation of the water contained in the pores of the clay begins, and, as it passes off, the particles of clay draw closer together, causing a shrinkage of the mass. This will continue until all the particles come in contact, but since they do not fit together perfectly, there will still be some spaces left between the grains, and these will hold moisture, which cannot be driven off except by gentle heating. The air shrinkage may, therefore, cease before all the water has passed off.

The amount of air shrinkage is usually low in lean clays, and high in very plastic ones, for the reason that the latter absorb considerable water in mixing, which they give off in drying. At the same time, however, it must be noted that all clays which require a high percentage of water in mixing, do not show a high air shrinkage.

The air shrinkage of a clay will not only vary with the amount of water added, but also with the texture of the material. Soft-mud bricks may shrink more than stiff-mud ones, because in the latter cases less water is added to the clay, and it is melted under greater pressure. At the same time the shrinkage of many soft-mud bricks is low, because much sand is often added to the clay. The low shrinkage of some sandy clays is seen in the case of Nos. 1322 and 1363, in the table opposite page 131.

While coarse or sandy clays shrink less than fine-grained ones, they may sometimes absorb considerable water, especially if they are silty in their character, but the fact that their pores are much coarser allows the water to escape rapidly, and thus often permits more rapid drying. The cracking of some fine-grained clays in drying is due partly to the surface shrinking more rapidly than the interior, because the evaporation there is greatest. As the outer portion of the product cannot stretch, it must pull apart and crack.

Fire shrinkage.— All clays shrink during some stage of the burning operation, even though they may expand slightly at certain temperatures. The fire shrinkage varies within wide limits,

the amount depending partly on the quantity of volatile elements, such as combined water, organic matter and carbon dioxide present in the clay, and partly on the texture. It reaches a maximum when the clay vitrifies, but does not increase uniformly up to that point, and, in fact, is very irregular. Thus a certain amount of shrinkage takes place when the combined water begins to pass off, namely, at 400°C. (752°F.), and an additional amount occurs at higher temperatures, but not apparently the result of contraction following volatilization of some of the elements.

Wherever the fire shrinkage is given in this report, it refers to the linear shrinkage occurring during burning, and is expressed in terms of the length of the bricklet when molded. Thus, if the fire shrinkage at cone 1 is given as 4 per cent., it means that the amount of fire shrinkage at that cone is 4 per cent. of the length of the bricklet when freshly molded.

Referring to the samples tested for the present report (see table, opposite page 131), Nos. 1300 and 1335 have a low fire shrinkage on account of their sandy character; No. 1356 has a high fire shrinkage, owing to its highly plastic character; Nos. 1313 and 1326 show the increase in shrinkage up to the point of vitrification, beyond which the clay begins to swell somewhat as shown by the decreased fire shrinkage.

Since many clays when used alone shrink to such an extent as to cause much loss from warping and cracking, it is necessary to add materials which have no fire shrinkage, and so decrease the shrinkage of the mixture in burning. Sand or sandy clays are the materials most commonly used for this purpose, but ground bricks (grog) and even coke or graphite may be employed. These materials serve not only to decrease the shrinkage in drying and burning, but also tend to prevent blistering in an easily fusible ferruginous clay when hard fired. They furthermore add to the porosity of the ware, and thus facilitate the escape of the moisture in drying and in the early stages of burning, as well as enable the product to withstand sudden changes of temperature. If sand is added for this purpose, it may act as a flux at high temperatures, and this action will be the more intense the finer its grain.

Large particles of grog are undesirable, especially if they are angular in form, because, in burning, the clay shrinks around them, and the sharp edges, serving as a wedge, open cracks in the clay,

which may expand to an injurious degree. Large pebbles will do the same, and at many of the common brickyards in the State, the writer has seen numbers of bricks split open during the burning because of one large quartz pebble left in the clay, as the result of improper screening of the tempering sand. For common brick, the type of sand used does not make much difference, as long as it is clean, but if sand is to be added to fire brick mixtures, it should be coarse, clean, quartz sand. Burned clay grog is more desirable than sand for high-grade wares, since it does not affect the fusibility of the clay, or swell with an increase of temperature as sand does, but precaution should be taken to burn the clay to its limit of shrinkage before using it.

FUSIBILITY.—When clays are heated to a temperature of 1000°C. they show little or no fire shrinkage, but there is another important change which takes place, namely, expulsion of volatile matter, such as, chemically combined water contained in kaolinite, limonite, or mica. In this interval much carbonaceous matter, if present, also burns off.

The rapidity with which the latter is driven from the clay depends on its condition, that is to say whether it is present as volatile carbon or fixed carbon. Of these two, the former burns off more readily.

From what has just been said, it is easily seen that the volatilization of the substances mentioned must necessarily leave the clay in a somewhat porous condition, until fire shrinkage again begins at 1000°C. or a little above.

A clay should, therefore, be heated slowly up to 600°C. (1112°F.) but from that point up to 1000°C. (1832°F.), the temperature can be rapidly raised unless much carbonaceous matter is present. (See Carbon in Clay.)

When a clay is heated, its hardness slowly increases until it finally reaches that of steel, or, in other words, cannot be scratched by a knife. This simply means that the clay particles have become so cemented by fusion that none can be scratched loose by a piece of steel.

The reaching of steel hardness by the clay does not mean vitrification, for many bricks are still porous. The temperature at which steel hardness occurs varies with the character of the material,

in pure easily fusible clays becoming so at a low temperature, such as cone 05, while others, such as kaolins, will not become steel-hard before cone 5 or possibly 8.*

Most clays soften slowly when heated, until they melt completely or run. Since the softening of clays under heat is comparatively slow, three stages are commonly recognized, termed, respectively, incipient fusion, vitrification, and viscosity.

The first of these expresses a condition in which the clay has softened just enough to make most of the particles stick together.

The second indicates a condition in which the clay particles have softened sufficiently to pack together and practically close up all the pores; and since it represents a stage of greatest compactness it is also the point of maximum shrinkage.

The third represents a stage at which the clay particles have softened so that the mass no longer holds its shape but runs.

It is sometimes difficult to recognize precisely the exact attainment of these three conditions, for the clay may soften so slowly that the change from one to the other is very gradual.

The difference in temperature between the points of incipient fusion and viscosity varies with the composition of the clay. In many calcareous clays these points are within 27.7°C. (50°F.) of each other, while in refractory clays they may be 377.7°C. (700°F.) to 444.4°C. (800°F.) apart. The glass-pot clays which are refractory but still burn dense at a comparatively low temperature, approach the last mentioned condition quite closely.

It is of considerable practical importance to have the points of incipient fusion and viscosity well separated, because in the manufacture of many kinds of clay products the ware must be vitrified or rendered impervious. If, therefore, the temperature interval between the points of vitrification and viscosity is great, it will be safer to bring the ware up to a condition of vitrification without the risk of reaching the temperature of viscosity and melting all the wares in the kiln, because it is impossible to control the kiln temperature within a range of a few degrees. In many clays the point of vitrification seems to be midway between that of incipient fusion and viscosity, but in others it is not.

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* For description of Seger cones see p. 79 of this chapter.

Several of the Pleistocene Coastal Plain clays, which were tested, soften with sufficient slowness to warrant their trial for vitrified products.

Temperature of fusion.— The temperature at which a clay fuses depends on: (1) The amount of fluxing impurities; (2) the condition of the fluxes; (3) the size of the grains; and (4) the condition of the kiln atmosphere, whether oxidizing or reducing.

1. Other things being equal, the temperature of fusion of a clay will fall with an increase in the percentage of total fluxes. If we compare the analyses of a brick clay and a fire clay we shall find that the analysis of the former shows perhaps 12 or 15 per cent. of fluxing or fusible ingredients, while that of the latter may show only 2 or 3 per cent., and that their fusion points are perhaps 1093°C. (2000°F.) and 1644°C. (3000°F.) respectively. All fluxing impurities do not, however, act with equal energy, some being more active than others.

2. The condition of chemical combination may also affect the result. Thus lime, for example, will induce a fluxing action in clay at a lower temperature if present in the form of carbonate of lime than as silicate.

3. The size of the mineral grains in clay undoubtedly exerts more effect than some investigators have been willing to admit. Other things being equal, a fine-grained clay will fuse at a lower temperature than a coarse-grained one, for the reason that when the particles of a clay begin to fuse or flux with each other, this action begins on the surface of the grains and works inward towards the center. If, therefore, the easily fusible grains are of small size, they fuse more rapidly, and are more effective in their fluxing action than if the grains were large. Since some of the mineral grains in the clay are more refractory than others, the clay in the earlier stages of fusion can be regarded as a mixture of fused particles, with a skeleton of unfused ones. If the proportion of the former to the latter is very small there will be a strong hardening of the clay with little shrinkage, and the burned clay will still be porous. With an increase of temperature, and the fusion of more particles, the pores fill up more and more, and the shrinkage

goes on until, at the point of vitrification, the spaces are completely filled. Above this point there is no longer a sufficiently strong skeleton to hold the mass together, and the clay begins to flow. The conditions which influence the difference in the temperature between vitrification and viscosity still remain to be satisfactorily explained, but it probably depends on the relative amounts of fluxes and nonfluxes and the size of grain of the latter.

4. Finally, it is found that the same clay will fuse at a lower temperature, if in burning it is deprived of oxygen, than it will if burned in an atmosphere containing an abundance of the latter.

Classification of clays based on fusibility.—The fact that different clays fuse at different temperatures makes it possible to divide them into several different groups, the divisions being based on the degree of refractoriness of the material. Such a grouping, however, is more or less arbitrary, since no sharp natural lines can be drawn between the different groups, and it is to be expected that no grouping proposed will meet with universal approval.

The following classification of clays, based on refractoriness, has been suggested by the writer:*

1. *Highly refractory clays,* those whose fusing point is above cone 33. Only the best of the so-called No. 1 fire-clays belong to this class.

2. *Refractory clays,* those whose fusion point ranges from cone 31-33 inclusive.

3. *Semi-refractory clays,* those whose fusion point lies between cone 27 and 30 inclusive.

4. *Clays of low refractoriness,* those whose fusion point lies between cone 20 and 26 inclusive.

5. *Nonrefractory clays,* fusing below cone 20.

The Coastal Plain clays in Virginia all fall in groups 4 and 5.

Determination of fusibility.— The temperature at which a clay fuses is determined either by means of test pieces of known composition, or by some form of apparatus or mechanical pyrometer, the principle of which depends on the expansion of gases or solids, thermo-electricity, spectro-photometry, etc.

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* New Jersey Geological Survey, Final Report 1904, Vol. VI, p. 100.

Seger cones.— These test pieces consist of a series of mixtures of clay with fluxes, so graded that they represent a series of fusion points, each being but a few degrees higher than the one next to it. They are so called because originally introduced by H. Seger, a German ceramist. The materials which he used in making them were such as would have a constant composition, and consisted of washed Zettlitz kaolin, Rörstrand feldspar, Norwegian quartz, Carrara marble, and pure ferric oxide. Cone No. 1 melts at the same temperature as an alloy composed of one part of platinum and nine parts of gold, or at 1150°C. (2102°F.). Cone 20 melts at the highest temperature obtained in a porcelain furnace, or at 1530°C. (2786°F.). The difference betwen any two successive numbers is 20°C. (36°F.), and the upper member of the series is cone 36, which is composed of a very refractory clay slate, while cone 35 is composed of kaolin from Zettlitz, Bohemia. A lower series of numbers was produced by Cramer, of Berlin, who mixed boracic acid with the materials already mentioned. Hecht obtained still more fusible mixtures by adding both boracic acid and lead in proper proportions to the cones. The result is that there is now a series of 58 numbers, the fusion point of the lowest being 590°C. (1094°F.), and that of the highest 1850°C. (3362°F.).

As the temperature rises, the cone begins to soften, and when its fusion point is reached it begins to bend over until its tip touches the base.

For practical purposes these cones are very successful, though their use has been somewhat unreasonably discouraged by some. They have been much used by foreign manufacturers of clay products and their use in the United States is increasing. The full series can be obtained from Messrs. Seger and Cramer, of Berlin, for $0.01 each (or about two and one-half cents apiece, including duty and expressage), or numbers .010 to 35 can be obtained for $0.01 each from Prof. E. Orton, Jr., of Ohio State University, Columbus, Ohio. The table of fusing points of these cones and their composition is given below:

Composition and fusing points of Seger cones.

Number of cone.		Composition.			Fusion Point. Cent.	Fusion Point. Fahr.
022		0.5 Na_2O 0.5 PbO		2 SiO_2 1 B_2O_3	590	1094
021		0.5 Na_2O 0.5 PbO	0.1 Al_2O_3	2.2 SiO_2 1 B_2O_3	620	1148
020		0.5 Na_2O 0.5 PbO	0.2 Al_2O_3	2.4 SiO_2 1 B_2O_3	650	1202
019		0.5 Na_2O 0.5 PbO	0.3 Al_2O_3	2.6 SiO_2 1 B_2O_3	680	1256
018.	Dull red heat	0.5 Na_2O 0.5 PbO	0.4 Al_2O_3	2.8 SiO_2 1 B_2O_3	710	1310
017		0.5 Na_2O 0.5 PbO	0.5 Al_2O_3	3.0 SiO_2 1 B_2O_3	740	1364
016		0.5 Na_2O 0.5 PbO	0.55 Al_2O_3	3.1 SiO_2 1 B_2O_3	770	1418
015		0.5 Na_2O 0.5 PbO	0.6 Al_2O_3	3.2 SiO_2 1 B_2O_3	800	1472
014		0.5 Na_2O 0.5 PbO	0.65 Al_2O_3	3.3 SiO_2 1 B_2O_3	830	1526
013		0.5 Na_2O 0.5 PbO	0.7 Al_2O_3	3.4 SiO_2 1 B_2O_3	860	1580
012.	Cherry red heat	0.5 Na_2O 0.5 PbO	0.75 Al_2O_3	3.5 SiO_2 1 B_2O_3	890	1634
011		0.5 Na_2O 0.5 PbO	0.8 Al_2O_3	3.6 SiO_2 1 B_2O_3	920	1688
010		0.3 K_2O 0.7 CaO	0.2 Fe_2O_3 0.3 Al_2O_3	3.5 SiO_2 0.5 B_2O_3	950	1742
09		0.3 K_2O 0.7 CaO	0.2 Fe_2O_3 0.3 Al_2O_3	3.55 SiO_2 0.45 B_2O_3	970	1778
08		0.3 K_2O 0.7 CaO	0.2 Fe_2O_3 0.3 Al_2O_3	3.60 SiO_2 3.40 B_2O_3	990	1814
07	Clear cherry red heat	0.3 K_2O 0.7 CaO	0.2 Fe_2O_3 0.2 Al_2O_3	3.65 SiO_2 0.35 B_2O_3	1010	1850
06	Clear cherry red heat	0.3 K_2O 0.7 CaO	0.2 Fe_2O_3 0.3 Al_2O_3	3.70 SiO_2 0.30 B_2O_3	1030	1886
05		0.3 K_2O 0.7 CaO	0.2 Fe_2O_3 0.3 Al_2O_3	3.75 SiO_2 0.25 B_2O_3	1050	1922
04		0.3 K_2O 0.7 CaO	0.2 Fe_2O_3 0.3 Al_2O_3	3.80 SiO_2 0.20 B_2O_3	1070	1958
03		0.3 K_2O 0.7 CaO	0.2 Fe_2O_3 0.3 Al_2O_3	3.85 SiO_2 0.15 B_2O_3	1090	1994
02		0.3 K_2O 0.7 CaO	0.2 Fe_2O_3 0.3 Al_2O_3	3.9 SiO_2 0.1 B_2O_3	1110	2030
01	Deep orange heat	0.3 K_2O 0.7 CaO	0.2 Fe_2O_3 0.3 Al_2O_3	3.95 SiO_2 0.05 B_2O_3	1130	2066
1	Deep orange heat	0.3 K_2O 0.7 CaO	0.2 Fe_2O_3 0.3 Al_2O_3	4 SiO_2	1150	2102
2	Deep orange heat	0.3 K_2O 0.7 CaO	0.2 Fe_2O_3 0.4 Al_2O_3	4 SiO_2	1170	2138
3	Deep orange heat	0.3 K_2O 0.7 CaO	0.5 Fe_2O_3 0.5 Al_2O_3	4 SiO_2	1190	2174
4	Deep orange heat	0.3 K_2O 0.7 CaO	0.5 Al_2O_3	4 SiO_2	1210	2210
5		0.3 K_2O 0.7 CaO	0.6 Al_2O_3	5 SiO_2	1230	2246

Composition and fusing points—Continued.

Number of cone.		Composition.				Fusion Point. Cent.	Fahr.
6	0.3 K_2O 0.7 CaO	0.7	Al_2O_3	6	SiO_2	1250	2282
7	0.3 K_2O 0.7 CaO	0.7	Al_2O_3	7	SiO_2	1270	2318
8	0.3 K_2O 0.7 CaO	0.8	Al_2O_3	8	SiO_2	1290	2354
9. White heat	0.3 K_2O 0.7 CaO	0.9	Al_2O_3	9	SiO_2	1310	2390
10	0.3 K_2O 0.7 CaO	1.0	Al_2O_3	10	SiO_2	1330	2426
11	0.3 K_2O 0.7 CaO	1.2	Al_2O_3	12	SiO_2	1350	2462
12	0.3 K_2O 0.7 CaO	1.4	Al_2O_3	14	SiO_2	1370	2498
13	0.3 K_2O 0.7 CaO	1.6	Al_2O_3	16	SiO_2	1390	2534
14 Bright white heat	0.3 K_2O 0.7 CaO	1.8	Al_2O_3	18	SiO_2	1410	2570
15	0.3 K_2O 0.7 CaO	2.1	Al_2O_3	21	SiO_2	1430	2606
16	0.3 K_2O 0.7 CaO	2.4	Al_2O_3	24	SiO_2	1450	2642
17	0.3 K_2O 0.7 CaO	2.7	Al_2O_3	27	SiO_2	1470	2678
18	0.3 K_2O 0.7 CaO	3.1	Al_2O_3	31	SiO_2	1490	2714
19 Dazzling white heat	0.3 K_2O 0.7 CaO	3.5	Al_2O_3	35	SiO_2	1510	2750
20 Dazzling white heat	0.3 K_2O 0.7 CaO	3.9	Al_2O_3	39	SiO_2	1530	2786
21 Dazzling white heat	0.3 K_2O 0.7 CaO	4.4	Al_2O_3	44	SiO_2	1550	2822
22 Dazzling white heat	0.3 K_2O 0.7 CaO	4.9	Al_2O_3	49	SiO_2	1570	2858
23	0.3 K_2O 0 7 CaO	5.4	Al_2O_3	54	SiO_2	1590	2894
24	0.3 K_2O 0.7 CaO	6.0	Al_2O_3	60	SiO_2	1610	2930
25	0.3 K_2O 0.7 CaO	6.6	Al_2O_3	66	SiO_2	1630	2966
26	0 K_2O 0.7 CaO	7.2	Al_2O_3	72	SiO_2	1650	3002
27	0.3 K_2O 0.7 CaO	2.0	Al_2O_3	200	SiO_2	1670	3038
28			Al_2O_3	10	SiO_2	1690	3074
29			Al_2O_3	8	SiO_2	1710	3110
30			Al_2O_3	6	SiO_2	1730	3146
31			Al_2O_3	5	SiO_2	1750	3182
32			Al_2O_3	4	SiO_2	1770	3218
33			Al_2O_3	3	SiO_2	1790	3254
34			Al_2O_3	2.5	SiO_2	1810	3290
35			Al_2O_3	2	SiO_2	1830	3326
36			Al_2O_3	2	SiO_2	1850	3362

If the heat is raised too rapidly the cones which contain much iron swell and blister and do not bend over, so that the best results are obtained by the slow softening of the cone under a gradually rising temperature. In actual use they are placed in the kiln at a point where they can be watched through a peep-hole, but at the same time will not receive the direct touch of the flame from the fuel. It is always well to put two or more cones of different numbers in the kiln, so that warning can be had, not only of the end point of firing, but also of the rapidity with which the temperature is rising.

In determining the proper cone to use in burning any kind of ware, several cones are put in the kiln, as, for example: numbers .08, 1 and 5. If .08 and 1 are bent in burning and 5 is not affected, the temperature of the kiln is between 1 and 5. The next time numbers 2, 3 and 4 are put in, and 2 and 3 may be fused, but 4 remains unaffected, indicating that the temperature reached the fusing point of 3.

The cone numbers used in different branches of the clay working industry are as follows:

Common brick	010—01
Hard-burned, common brick	1— 2
Buff front brick	6— 8
Hollow blocks and fireproofing	03— 1
Terra cotta	04— 7
Conduits	7— 8
White earthenware	8— 9
Fire bricks	9—12
Porcelain	11—13
Red earthenware	010—05
Stoneware	6— 8

While the temperature of fusion of each cone number is given in the preceding table, it must not be understood that these cones are for measuring temperature, but rather for measuring pyrochemical effects. Thus if certain changes are produced in a clay at the fusing point of cone 5, the same changes can be reproduced at the fusion point of this cone, although the actual temperature of fusion may vary somewhat, due to variation in the condition of the kiln atmosphere. As a matter of fact, however, repeated tests with a thermo-electric pyrometer demonstrate that the cones commonly fuse close to the theoretic temperatures.

Manufacturers occasionally claim that the cones are unreliable and not satisfactory, forgetting that their misuse may often be the true reason for irregularities in their behavior. It is unnecessary, perhaps, to state that certain reasonable precautions should be taken in using these test pieces. The cones are commonly fastened to a brick with a piece of wet clay, and should be set in a vertical position. After being placed in a position where they can be easily seen through a peep-hole, the latter should not be opened wide during the burning, lest a cold draft strike the cones, and a skin forms on its surface and interferes with its bending. Moreover, one set of cones cannot be used to regulate an entire kiln, but several sets should be placed in different portions of the same kiln. One advantage posesssed by a cone over trial pieces is that the cone can be watched through a small peep-hole, while a larger opening must be made to draw out the trial piece. If the cones are heated too rapidly, especially those containing a large percentage of iron, they are apt to blister.

The best results with cones are obtained in closed kilns. They are not of much service in scove kilns, for the reason that the temperature in these is apt to be more or less irregular, there being no good means of watching them, and they are liable to be touched by cold drafts. If placed in such kilns, they should be carefully enclosed to protect them from flashing or drafts of cold air.

Thermo-electric pyrometer.— This pyrometer, which is the only one that will be described in this report, is one of the best instruments for measuring temperatures. It is based on the principle of generating an electric current by the heating of a thermopile or thermo-electric couple. This consists of two wires, one of platinum and the other of an alloy of 90 per cent. platinum and 10 per cent. rodium. The two are fastened together at one end, while the two free ends are connected with a galvanometer which measures the intensity of the current. That portion of the wires which is inserted into the furnace or kiln is placed within two fire-clay tubes, one of the latter being smaller and sliding within the other in order to insulate the wires from each other. The larger tube has a closed end to protect the wires from the action of the fire gases.

To measure the temperature of a furnace or kiln the tube containing the wires is placed in it either before starting the fire, or else during the burning. If the latter method is adopted, the tube must be introduced very slowly to prevent its being cracked by sudden heating. The degrees of temperature are measured by the amount of deflection of the needle of the galvanometer.

Thermo-electric pyrometers are useful for measuring the rate at which the temperature of a kiln is rising, or for detecting fluctuations in the same. It is not necessary to place the galvanometer near the kiln, for it can be kept in the office some rods away. This pyrometer is not to be used as a substitute for Seger cones but to supplement them. The more modern forms have an automatic recording device. As at present put on the market, the thermo-electric pyrometer costs about $180; and the price, delicacy of the instrument, and lack of realization of its importance, have tended to restrict its use. However, many of the larger clay-working plants are adopting it, as it is better than other forms of pyrometer for general use and probably more accurate. It can be used up to 1600°C. (2912°F.).

TEXTURE.—By the texture of a clay is meant its size of grain. Many clays contain sand grains of sufficient size to be visible to the naked eye, but the majority of clay particles are too small to be seen without the aid of a microscope, and are, therefore, so small that it becomes impossible to separate them with sieves. In testing the texture of a clay it is perhaps of sufficient importance for practical purposes, to determine the per cent. of any sample that will pass through a sieve of 100 or 150 meshes to the inch, since in the preparation of clays for the market by the washing process they are not required to pass through a screen any finer than the one above mentioned.

If it is desired to measure the size of all the grains found in the clay, some more delicate method of separation becomes necessary. In many clays the grains cohere more or less, forming compound ones, and these have to be disintegrated by some preliminary treatment, such as boiling, or, better still, by agitating.

COLOR.—An unburned clay owes its color commonly to some iron compound or carbonaceous matter; a clay free from either of these being white. Carbonaceous matter will color a clay gray or

black, depending on the quantity present; 3 to 4 per cent. being usually sufficient to produce a deep black. A sandy clay will, however, be more intensely colored by the same quantity than one with many clay particles.

Iron oxide colors a clay yellow, brown, or red, depending on the form of oxide present. The greenish color of many of the clay marls is due to the presence of the mineral glauconite. The iron coloration is, however, often concealed by the black coloration due to the carbonaceous matter. It is often more or less difficult to make even an approximate estimate of the iron content in a clay from its color.

Thus, for example, the bluish-black Miocene clay, collected from along the Atlantic Coast-Line Railway south of Chester, burns to a bright red color.

The color of a green or raw clay is not always an indication of the color it will be when burned. Red clays usually burn red; deep yellow clays burn red or buff; chocolate ones commonly burn red or reddish brown; white clays burn white or yellowish white; and gray or black ones may burn red, buff or white. Calcareous clays are often either red, yellow or gray, and may burn red at first, but turn yellow or buff as vitrification is approached.

Slaking.—When a lump of clay is thrown into water it falls to pieces or slakes but the rapidity with which this takes place varies greatly in different clays. Open, porous, sandy ones fall rapidly to a powdery mass; others may spall or chip off slowly when immersed; while still others either do not slake at all, or only after long soaking. The slaking property is one of some practical importance, as easy slaking clays temper more readily, or, if the material is to be washed, it disintegrates more rapidly in the long washer.

Specific gravity.—The specific gravity of a clay stands in more or less close relation to the density of its mineral particles, and affects its weight per cubic foot, but most clays do not vary much in their specific gravity, which ranges commonly from about 1.80 to 2.60. That is they weigh 1.80 to 2.60 times as much as an equal amount of water.

CHEMICAL AND PHYSICAL PROPERTIES OF THE COASTAL PLAIN CLAYS IN VIRGINIA.

Having discussed the chemical and physical properties of clays in general, it may be well to summarize those of the Virginia clays. During the course of the field work all the known deposits were visited and samples collected from many of them for physical tests and chemical analyses. Not a few of these deposits are being worked, and the question may be asked whether it pays to submit these to examination. In many cases it does, for the reason that the results of such a study suggests additional uses for the clay. At the present time the Virginia Coastal Plain clays are used for little else than the manufacture of common brick. For this purpose the clay is commonly burned at a very low temperature, sometimes under cone 010, which is not sufficiently high to bring out the vitrifying qualities of the material.

Physical properties.—The clays collected were all tested for: (1) Amount of water required to work them up; (2) slaking qualities; (3) plasticity by feel; (4) grit; (5) air shrinkage; (6) tensile strength; (7) fire shrinkage, color, and per cent. of absorption at seven cones, namely 010, 05, 03, 1, 3, 5, 8.

The amount of water required for mixing ranged from 18.7 per cent. to 62.4 per cent., with an average of 26.5 per cent. The maximum was shown by a sample of diatomaceous earth, which is very silty in its character, and the majority absorbed between 20 and 25 per cent. of water, which is not excessive.

Most of the clays tested slake fast or moderately fast, so that they temper rather easily. The plasticity is variable, depending usually on the amount of silt or sand present, but in many of the Pleistocene clays it is excellent, and entirely sufficient to permit of their being worked in an auger or a dry-press machine. At present, soft-mud machines, or hand methods unfortunately find the greatest favor.

The grit content of some of the Coastal Plain clays is considerable, in others it is very low, and even in the bank there may be variations from place to place. Not all of the clays of the same formation show uniformity in grade, those at one point being quite sandy, those at another point being quite free from sand. The air shrinkage of the different samples tested ranged from 1.6

per cent. to 14 per cent., with an average of 8.2 per cent.; and even in the sandy ones the air shrinkage was not low. At the same time it is in most cases not sufficiently high to cause any trouble.

The tensile strength of the clays tested ranged from 41.2 pounds per square inch up to 300.9 pounds per square inch with an average of about 130 pounds. Few of them had a high tensile strength and very few of them showed a very low tensile strength, so that in most cases the bonding power is entirely sufficient for the uses to which they are liable to be put. Considering the burning qualities of the clays we find that the majority of those tested burned to a red body, only three yielding a cream colored or buff product. These three were respectively a clay from Oldfield on the James river (Lab. No. 1312), a whitish clay from between Stafford and Fredericksburg (Lab. No. 1352), and a buff clay from southeast of Wilmont (Lab. No. 1365). As already stated, all of the others burned red or red-brown, the color increasing with the intensity of the fire.

When burned at cone 010 the fire shrinkage of nearly all was under 1 per cent., but the absorption as seen from the tabulated tests was in most cases not excessive, that is to say, the absorption of many of them at this cone is between 15 and 20 per cent., which is no more than that shown by many common brick of good strength. In examining the tables of the tests made at other cones it is noticed that the clays usually show a gradual shrinkage up to their points of vitrification, after which they begin to expand slightly. Some of the clays burned to a very dense body at a comparatively low cone. A few examples of this are given below.

Locality	Cone	Absorption Per Cent.
1 Mile North of Bermuda Hundred	1	0.12
Broadway	1	1.7
6 Miles South of Richmond	1	1.5
Sturgeon Point	1	2.80
Suffolk, Drab Clay	1	1.50

A clay on the Williamsburg road near Richmond (Lab. No. 1330) showed an absorption of only 5.65 when burned at as low a cone as 03, and one from the Ball property six miles south of Richmond (Lab. No. 1316) had only 4.7 absorption at cone 03. It is probable

that clays burning as dense as these at such low heats could perhaps be used in the manufacture of paving brick or possibly even common stoneware.

Chemical properties.—A complete chemical analysis was made of each sample for the purpose of determining the silica, alumina, iron oxide, lime, magnesia, potash, soda, titanic oxide, and water. Examining the silica contents, first we notice that many of the clays show a somewhat high silica percentage, and this would lead us to suppose that they had a very low air shrinkage which, however, is not always the case, as much of the silica seems to be present in the form of fine silt, which would reduce the air shrinkage less than if it were there as coarse sand grains. The silica content ranged from 51.12 up to 85.72, with an average of 68.74 per cent. Some of those running highest in silica are samples of diatomaceous earth which should not perhaps be classed with the clays, but it is done for the reason that the material is interbedded with the clay deposits and often is more or less clayey in its character, sometimes even passing into a bed of clay. The percentage of alumina ranged from 5.83 to 28.97 with an average of 16.62, and in many the percentage of alumina is somewhat higher than it often is in brick clays. The highest alumina content, namely, 28.97 was shown by the Miocene clay collected between Stafford and Fredericksburg at a point about six miles east of north from the latter town. The lowest alumina percentage was found in a greenish gray clay which outcrops along the bank of the Rappahannock river about 1 mile south of Layton on the property of Mr. Beverley. This clay, which is pretty gritty, had a very low tensile strength, and on account of its highly siliceous nature its fire shrinkage was very low, and, in fact, at cone 010 it swelled slightly. Its siliceous character and its low fire shrinkage were accompanied, as one might expect, by a high absorption.

Turning to the iron oxide percentages we find that these range from 1.74 to 10.70 with an average of 5.33 per cent. In almost every case the percentage of iron shown by the analyses indicates its red burning color, although there are one or two which are slightly misleading. Thus, for example, a gray clay from Oldfield (Lab. No. 1312) burns to a somewhat buff color, although it has an iron content of 3.49. The reason for this is probably due

to the fact that the iron is not uniformly distributed in the clay, a condition which cannot be told from the chemical analysis. Again, a clay from Suffolk (Lab. No. 1343) tends to burn to a somewhat buff color, although it has 3.17 per cent. of iron. The sample of clay from the House Bank southeast of Wilmont (Lab. No. 1365) burns to a pink cream at low temperatures but above cone 1 its color begins to deepen somewhat. This on analysis showed but 2.42 per cent. of iron.

It is interesting to note that nearly all of the clays tested contained a variable but usually small quantity of titanic oxide, which ranged from 0 up to 1.95 per cent. with an average of .44 per cent.

As an example of the variation which may occur in clays in different parts of the same bank, we can take numbers 1334, 1335, and 1336 of the table. These three clays all occur in the same bed, and the one grades into the other. No. 1334 works all right, gives a good color, and makes a good brick. No. 1335 is less satisfactory, for it does not give as sound a brick. No. 1336 is a very sandy clay, and makes a porous brick that lacks in ring. For purposes of comparison the physical tests and chemical analyses are given in parallel columns.

The difference in behavior of these clays is brought out quite well in the physical tests. The greater sandiness and low plasticity of No. 1336 is quite marked; it also required less water for mixing than No. 1334, but about the same quantity as 1335. The air shrinkage decreases with the increase in the sand contents of the clay, No. 1334 being the least gritty and No. 1336 the most sandy. The same applies to the tensile strength or bonding power, that of 1336 being but little over half that of 1334.

When we examine the results of the fire tests, similar differences are found. No. 1334 burns to a brighter red color and denser body than either of the other two, and also has a higher fire shrinkage. The very sandy one which yields porous brick swells slightly at cone 010 and above that shows no shrinkage up to cone 5, above which it begins to diminish slowly in size.

The chemical analyses, although less expressive than the physical tests, nevertheless, show some differences. Thus we notice the increase in total silica from 1334 to 1336, and the decrease in alu-

	1334	1335	1336
Color	light brown	gray	gray
Water required	24.2	18.7	18.7
Slaking	mod. fast	fast	fast
Plasticity	fair	fair	low
Grit	sandy	sandy	sandy
Air shrinkage	8.3	6.0	5
Average tensile strength	144.2	105.1	79.8
Cone 010			
Fire shrinkage	.3	0	s. s.*
Color	light red	pink	pink
Absorption	17.7	15.7	15.08
Cone 05			
Fire shrinkage	1.6	.3	s. s.*
Color	light red	pink	light red
Absorption	14.7	14.5	14.0
Cone 03			
Fire shrinkage	3	1.3	0
Color	light red	light red	light red
Absorption	21.1	12.2	13.9
Cone 1			
Fire shrinkage	4.3	1.3	0
Color	red	light red	red
Absorption	8.2	10.3	12.90
Cone 3			
Fire shrinkage	5	2.6	0
Color	dark red	mottled red	light red
Absorption	6.6	9.3	12.3
Cone 5			
Fire shrinkage	4.6	2.3	0
Color	red gray	red	red
Absorption	5.0	7.86	10.91
Cone 8			
Fire shrinkage	5.0	3.6	1.3
Color	red brown	light brown	lt. brown
Absorption	.21	.31	6.50
Silica (SiO_2)	69.75	74.55	77.78
Alumina (Al_2O_3)	17.13	15.43	12.84
Ferric oxide (Fe_2O_3)	4.67	3.07	3.05
Lime (CaO)	.53	.43	.40
Magnesia (MgO)	.31	.65	.29
Potash (K_2O)	1.89	1.42	1.69
Soda (Na_2O)	.56	1.16	.44
Titanic oxide (TiO_2)	.06	.22	.20
Water (H_2O)	5.07	3.03	3.24
Total fluxes	7.96	6.73	5.87

*s. s.—Slightly swelled.

mina in the same direction. The brighter color burning quality of 1334 is due to a higher percentage of ferric oxide.

Bricks are sometimes made from clays running as high in silica as 1336 does, or even higher, but the product is usually porous and weak, and from the series analyzed and tested for this bulletin,

one might assume that 75 per cent. silica is as high as it is wise to go.

It will be noticed that most of the clays have to be burned up to cone 1 to show what they are really good for, as below this the majority are quite porous. In this connection it is interesting to note that of two clays, the one showing the lower absorption at one cone will not show the same condition at a higher cone; in other words they do not always densify at the same rate in the same temperature interval. Compare 1306 and 1330.

CHAPTER III.

EXPLOITING AND MINING CLAYS.

PROSPECTING FOR CLAYS.—While the methods used in searching for clays are simple, still, if the work is not thoroughly done, deposits are often easily overlooked.

Outcrops.—The presence of a clay bed is usually detected by means of an outcrop. These exposures are commonly to be found on inclined surfaces such as hill slopes, or where natural or artificial cuts have been made. The washing out of gullies by heavy rains; the cutting of a stream valley; railroad cuts and wagon-road cuts; all form good places in which to look for outcropping clay beds. The newer the cut, the better the exposure, for the sides of such excavations wash down rapidly, and a muddy-red surface clay or loam will often run down over a bed of lighter colored clay beneath, so as to completely hide it from view. If the cut is deep and freshly made, the depth of weathering can frequently be determined

Springs.—In many cases the presence of clay is shown by the occurrence of one or more springs issuing from the same level along some hill slope. These are caused by waters seeping down from the surface, until they reach the top of some impervious clay stratum, which they then follow to the face of the bank where they issue. The presence of springs, however, cannot be used as a positive indication of clay, for a bed of cemented iron sand, or even dense silt, may produce the same effect. In the Coastal Plain area, the best exposures are usually found along the rivers, such as the James, Appomattox, Rappahannock, York, etc., but even

here the banks become so low as the coast is approached, that exposures are rare. Moreover, along the coast there is often a more or less continuous covering of sand which tends to obscure the clay deposits.

Exploitation.—The location of a clay deposit is followed by a determination of its thickness, extent, character and uses. The first two points and some facts bearing on the third are determined in the field; the behavior of the clay when mixed up and burned is found out by tests made in the laboratory or at some factory; and the information thus obtained indicates the commercial value of the material.

To determine the thickness and extent of the deposit, a careful examination should be made of all clay outcrops in neighboring gullies, or other cuts on the property having the clay. Since, however, most clay slopes wash down easily, it may be necessary to dig ditches from the top to the bottom of the cut or hillside in order to uncover the undisturbed clay beds. In most cases, however, the cuts are not sufficiently close together and additional means have to be taken to determine the thickness of the deposit at intermediate points. Such data are sometimes obtainable from wells or excavations made for deep cellars, but the information thus obtained has to be taken on hearsay evidence. Borings made with an auger furnish a more satisfactory and rapid means of determining the thickness of the clay deposit away from the outcrop.

From comparison of the data obtained from the bore holes and outcrops, any vertical or horizontal variations in the deposit can usually be traced. Limonite concretions or crusts, if present in any abundance, are almost sure to be discovered, and even the dryness of the beds can be ascertained. Variations in the thickness of the bed and amount of stripping are also determinable. If small samples are desired for laboratory testing these can be taken from the outcrops and bore holes, but if large samples are wanted from the intermediate points it is best to sink test pits where the borings are made.

Winning the clay.—Having determined the thickness, extent and character of the clay, there still remains several important points which have to be considered.

One of these is the amount of stripping. Unless the clay is of high grade it will not pay to remove much overburden unless the

latter can be used. It is sometimes utilized for filling where the factory is to be erected next to the bank, or for admixture with the clay, especially if the latter is too plastic or fat. In such event, however, the overburden should be free from pebbles, or, if not, it should be screened. Frequent neglect of this often injures the bricks. If the overburden is sand, there is in some localities a market for it for foundry use, building or other purposes.

Drainage facilities must be looked out for, since dryness is essential for successful and economic working of the clay bed. In some districts, the clay is underlain by a stream of wet sand, which should not be penetrated.

If the clay deposit lies below the level of the surrounding country, drainage will be more difficult than where the bed outcrops on a hillside, although in the latter case trouble may be and often is caused by springs.

Some banks contain several different grades of clay, and it then remains to see whether they are all of marketable character, or if not, whether the expense of separating the worthless clay will overbalance the profit derived from the salable earth.

Transportation facilities are not to be overlooked, either for the raw clay or for the product, where the factory is located at the pit or bank. Long haulage with teams is costly, and steam haulage is far more economical when the output warrants it. But even with the establishment of favorable conditions in every case, the successful marketing of the product is sometimes a long and tedious task, for many manufacturers hesitate to experiment with new clays.

Methods of Mining.—The methods of mining employed are slightly different for clays and shales, the latter on account of their greater hardness requiring stronger machinery. All that follows below regarding mining methods will apply to clay.

1. *Underground workings.*—This method may be resorted to when the clay bed is covered by such a great thickness of overburden that its removal would be too costly. If the bed sought outcrops on the side of a hill, a tunnel or drift is driven in along the clay bed; but in case no outcrop is accessible, it is necessary to sink a vertical shaft until the bed of clay is reached, and from this, levels

or tunnels may be driven along the clay bed. Underground methods are desirable, however, only under certain conditions, which may be enumerated as follows:

1. In the case of high-grade clays.

2. Where there is much overburden as compared with the thickness of the clay deposit.

3. There should, if possible, be a solid dense layer overlying the clay stratum, otherwise the expense of timbering for supporting the roof may be too great. Where the clay is not interstratified between dense water-tight beds, it is often necessary to leave the upper and lower foot of clay to form a roof and floor.

4. The workings should be free from water, both on account of the cost of removing the same and because of the tendency of wet ground to slide.

5. The output is usually restricted, unless the workings underlie a large area, and can be worked by several shafts or drifts.

No underground mining for clay is done in the Virginia Coastal Plain area nor would it be practicable.

Surface working.—This consists in digging the material from open pits or cuts of variable size. Where the pit is small, it is commonly the custom to use picks and shovels to dig the clay (Pl. XI, Fig. 2.); and, indeed, this method is necessary in those cases where the clay is not of uniform quality from top to bottom, or when the bank contains a number of layers of different kinds. It is then necessary to strip off each one separately and place it in a separate storage pile or bin.

The cost of removing the stripping will depend on its character, whether hard or soft, the distance to be moved, and the possibility of its being used for any purpose, such as filling or grading. The methods of removal employed will also affect the expense. If the thickness of the overburden is considerable, and a large quantity has to be removed, it is cheaper to dig it with a steam shovel than by hand. Wheel scrapers are also employed at times, and, if the distance to the dump heap is short, the material can be carried there in the scraper. If the stripping can be used to mix with the clay, it is sometimes dug with shovels and screened to free it from pebbles. A method tried at some localities is to remove the sandy or gravelly overburden by washing. This is done by directing a powerful stream of water from a hose against the

face or surface of the gravel and washing it down into some ditch along which it runs off.

In selecting a site for a dump heap, care should be taken not to locate it over any clay deposit which is to be worked out later, but the presence or absence of such clay under the proposed dump can commonly be determined by a few bore holes made with an auger.

Where there is danger of the pit caving in, the sides are sometimes protected in the weak parts by planking, held in place by cross timbers.

Where a pit is dug so deep that it is not possible for the workman to throw or lift the lumps to the surface of the ground, a platform may be built in the pit, halfway up its side, or else the clay is loaded into buckets and hoisted to the surface by means of a derrick operated by steam- or horse-power.

When the clay lies above the ground or road level, there is less trouble with the water, and it is not necessary to work the clay in pits, although the general system of working forward in a succession of pit-like excavations or recesses is followed. In such banks, the cart or car is backed against the face of the excavation and the clay thrown into it.

Unless a number of pits are being dug at the same time, the output of any one deposit or of any one grade is necessarily small, since five or six different kinds are sometimes obtained from one pit. It would also seem that by this method any one grade of clay might show greater variation than if the excavation were more extended, for the reason that since clay beds are liable to horizontal variation the material extracted from one pit might be different from that taken from another farther on. Against this we may, of course, argue that the clays from different pits get mixed up on the storage pile. The surface drainage is commonly diverted by means of ditches dug around the top of the pit. In some districts there is a bed of water-bearing sand underlying the lowest clay dug, and, as this is approached, hand pumps have to be used to keep down the water until the last spit of clay is all taken out.

When clay deposits are worked as a bank or large pit, the clay is commonly dug by means of pick and shovel, but if the scale of operations warrants, a steam shovel is far better and more economical. If the clay is tough, the material is sometimes loosened by

means of a blast, but more often by undermining or falling. This is done by digging a narrow cut into the bank at its base, and then driving in a line of wedges on top, one or two feet from the edge. In this manner large masses weighing many tons are pried off and break in falling.

Steam shovels are much used in some of the clay pits around Alexandria, where a large area has been worked over.

Pit mining for kaolin.—Some clays, like kaolin, occur in vein-like deposits, which are narrow as compared with their length, and have to be mined by special methods. In these a circular pit of about 25 ft. diameter is dug, and sunk to the bottom of the clay. The sides of the pit are supported by a crib work of short timbers which are anchored every four feet. When the clay has been dug out the pit is filled in, and a new one started next to it. The old pit is filled, if possible, by stripping removed in digging the new one. Such pits are sometimes dug to a depth of over 100 feet.

PREPARATION OF CLAY AFTER MINING.—For most grades of clay products, the clay is run from the bank directly to the machine, but where used for the better grades of clay ware, some preparation is oftentimes necessary.

Large concretions, pyrite nodules and lumps of lignite are often picked out by hand and thrown to one side. Where the impurities are present in a finely divided form and distributed throughout the clay, screening or hand picking may be ineffective, and washing is necessary.

Washing.—The method of washing most commonly adopted is the troughing method, in which the clay, after being stirred up and disintegrated with water, is washed into a long trough along which it passes, dropping its sandy impurities on the way and finally reaching the settling vats, into which the clay and water are discharged, and where the clay finally settles.

Details.—The disintegration of the clay is generally accomplished in washing troughs. These consist of cylindrical or rectangular troughs, in which a shaft revolves, bearing a series of arms or stirrers. The clay, after soaking a short time in a pit, is shoveled into the washer, into which a stream of water is also directed, and the revolving blades break up the clay so that it goes more readily into suspension. The water, with suspended clay, then passes out at the opposite end from which the water entered.

The troughing into which the material is discharged is constructed of plank and has a rectangular cross-section. Its slope is very gentle, not more than 1 inch in 20 feet, usually; and its total length may be from 500 to 700 feet, or even 1,000 feet. In order to economize space, it is usually built in short lengths, which are set side by side, and thus the water and clay follow a zigzag course. The pitch, width and depth of the troughing may be varied to suit the conditions, for at some localities it is necessary to remove more sand than at others. If the clay contains much very fine sand, the pitch must be less than if the sand is coarse, since fine sand will not settle in a fast current. In the case of very sandy clays, it is customary to place sand wheels at the upper end of the troughing. These are wooden wheels bearing a number of iron scoops on their periphery. As the wheel revolves the scoops pick up the coarse sand which has settled in the trough, and, as the scoop reaches the upper limit of its turn on the wheel, by its inverted position, it drops the sand upon a slanting chute, which carries it outside the trough.

By the time the water reaches the end of the troughing, nearly all the sand has been dropped and the water and clay are discharged into the settling tanks; passing first, however, through a screen of about 80 or 100 mesh. This catches any particles of dirt or twigs and thus keeps the clay as clean as possible.

The settling tanks are of wood, usually about 4 feet deep, 8 feet wide and 20 to 50 feet long. As soon as one is filled, the water and clay is diverted into another. When the clay has settled, most of the clear water is drawn off, and the cream-like mass of clay and water in the bottom of the vat is drawn off by means of slip pumps and forced into the presses. These consist of flat iron or wooden frames, between which are flat canvas bags. The latter are either connected by nipples with the supply tubes, or else there may be a central opening in all the press bags and frames, which, being in line, form a central tube when the press is closed up. By means of pressure from the pumps, the slip is then forced into the press, and the water is also driven out of it. It commonly takes about two hours to fill a press. When the water has been squeezed out, the press is opened, and the sheets of clay are removed from the press cloths and sent to the drying room or racks.

In Virginia the washing of clays is practised only at kaolin mines.

CHAPTER IV.

THE MANUFACTURE OF CLAY PRODUCTS.

INTRODUCTION.

Although many persons are familiar with the wide distribution of clay, yet few appreciate its value or the wide variety of uses to which it is put. All recognize its application to brick manufacture, and table or toilet ware, but here the knowledge of its value often ceases. Even the lower grades of clay have a wide variety of uses.

USES OF CLAY.—Since the owners of clay property are often desirous of knowing to what uses clays can be put, the following table is given:*

Domestic.—Porcelain, white earthenware, stoneware, yellow ware and Rockingham ware for table service and for cooking; majolica stoves; polishing brick, bath brick, fire kindlers.

Structural.—Brick; common, front, pressed, ornamental, hollow, glazed, adobe; terra cotta; roofing tile; glazed and encaustic tile; drain tile; paving brick; chimney flues; chimney posts; door knobs; fire proofing; terra-cotta lumber; copings; fence posts.

Hygienic.—Urinals; closet bowls; sinks; wash-tubs; bath-tubs; pitchers; sewer pipe; ventilating flues; foundation blocks; vitrified bricks.

Decorative.—Ornamental pottery; terra cotta; majolica garden furniture; tombstones.

Minor uses.—Food adulterants; paint fillers; paper filling; electric insulators; pumps; fulling cloth; scouring soap; packing for horses' feet; chemical apparatus; condensing worms; ink bottles; ultramarine manufacture; emery wheels; playing marbles; battery cups; pins, stilts and spurs, for potters' use; shuttle eyes and thread guides; smoking pipes; umbrella stands; pedestals; filter tubes; caster wheels; pump wheels; electrical porcelain; foot rules; plaster; alum.

Refractory wares.—Crucibles and other assaying apparatus; gas retorts; fire bricks; glass pots; blocks for tank furnaces; saggers; stove and furnace bricks; blocks for fire boxes; tuyeres; cupola bricks; mold linings for steel castings.

* Hill, Mineral Resources, U. S. Geological Survey, 1891, p. 475.

Engineering works.—Puddle; Portland cement; railroad ballast; water conduits; turbine wheels; electrical conduits; road metal.

CLASSIFICATION OF CLAYS.—The classification of clays may be based on their uses, origin, or physical and chemical properties; any of which are more or less unsatisfactory. Certain variety names are often used, which are more indicative of the physical characteristics of the clay than its application. Many of these are given below.

Kaolin.—A term applied to white-burning residual clays, used in the manufacture of white earthenware, porcelain, wall tiles, white floor tiles, paper making, etc. White burning sedimentary clays are referred to by a few as plastic kaolins.

Ball clays.—White-burning, plastic, sedimentary clays, employed chiefly in the manufacture of the finer grades of pottery, namely, those having a white body.

Fire clays.—A term loosely applied to clays considered suitable for making fire brick. No standard of refractoriness has been adopted in this country, and many clays are called fire clays which have absolutely no right to the name. A classification of fire clays is suggested by the writer under fusibility.

Stoneware clays.—Under this term are included such clays as are adapted to the manufacture of stoneware. They must show good plasticity, dense-burning qualities and good tensile strength. The lower grades of stoneware are often made from a non-refractory clay, but the better grades are generally made from a No. 2 fire clay.

Sagger clays.—This is a term applied to clays which are used for making saggers, in which white ware and other high grades of pottery or tiles are burned. The clays employed vary in their character; they must be of sufficient refractoriness to hold their shape at the temperature at which they are burned. None of those seen in the Coastal Plain are adapted to this purpose.

Terra cotta clay.—This term does not mean very much and is used rather indiscriminately to indicate different kinds of clays, which are being dug for the manufacture of terra cotta. Most of the clays used for this purpose are semi-refractory, and buff-burning, sometimes sandy, at other times dense burning. Red-burning

clays are but little used now in terra-cotta bodies, and the Coastal Plain clays so far as known are not well adapted to this purpose.

Retort clay.—A dense-burning, plastic, semi-refractory clay, used chiefly in the manufacture of stoneware.

Pipe clay.—This term is a loose one, applied to almost any fine-grained plastic clay. Strictly speaking, it would refer to a clay used for sewer pipe.

Brick clay.—This includes all impure, non-refractory clays adapted to the manufacture of common brick. The less sandy kinds are often used for drain tile.

Paper clay includes many white, fine-grained clays, which are used for filling paper.

Paving brick clay.—This includes both clays and shales of red burning character, and of such a composition and texture that they can be vitrified.

THE METHODS OF MANUFACTURE.

In the present report are considered only the manufacture of those products which could probably be made from clays occurring within the Coastal Plain area of Virginia. This, therefore, includes common and pressed brick, paving brick, drain tile, roofing tile, fire proofing, low grade fire brick, red earthenware, and stoneware. From this it will be seen that such products as terra cotta, sewer pipes, floor and wall tiles, white earthenware and porcelain are omitted.

THE MANUFACTURE OF BUILDING BRICK.

Building brick include common, face, and pressed brick, enamel brick and glazed brick. A consideration of the last two is excluded from this report. Common brick include all those used for ordinary structural work, and are employed commonly for side and rear walls of buildings, or, indeed, for any portion of the structure where appearance is of minor importance, although for the sake of economy they are often used for front walls. They are usually made without much regard to color, smoothness of surface, or sharpness of edges.

Face, front, or pressed brick, includes those made with greater care, and usually from a better grade of clay, much consideration being given to their uniformity of color, even surface and straightness of outline.

RAW MATERIALS.

Clays for common brick.—The clays used for common brick are usually of a low grade, that is they contain a large amount of impurities, and are often gritty. Except in certain districts, those selected are almost invariably red-burning. The main requisites are that they shall mold easily and burn hard at as low a temperature as possible, with a minimum loss from cracking and warping. Few brick clays are used as taken from the bank, but they are generally mixed with sand. In fact so much sand is sometimes added that the air shrinkage is not more than 2 or 3 per cent. Moreover, in burning, the temperature oftentimes does not exceed the fusion point of cone 012 or 011, so that the fire shrinkage is exceedingly low, and the firing not always intense enough to give a good hard brick.

Of course in some cases it is necessary to mix in some sand or sandy clay, as otherwise the mixture would be too tough to mold easily, and shrink too much in drying and burning. The blue bottom clay from Suffolk is a good example of a material which requires the addition of a less strong clay or sand. Some clays, however, are so tough, that it is difficult to thoroughly incorporate the materials added, without proper mechanical separation.

Common brick clays vary widely in their composition. Taking the analyses of all those dug and used for this purpose in the Virginia Coastal Plain we get the following figures:

CHEMICAL COMPOSITION OF SOME VIRGINIA COASTAL PLAIN BRICK CLAYS.

Constituents	Minimum	Maximum	Average
Silica (SiO_2)	51.12	85.72	68.74
Alumina (Al_2O_3)	5.83	28.97	16.62
Ferric oxide (Fe_2O_3)	1.74	10.70	5.33
Lime (CaO)	.00	1.46	.45
Magnesia (MgO)	.05	1.18	.38
Potash (K_2O)	.75	3.13	2:05
Soda (Na_2O)	.22	1.23	.72
Titanic oxide (TiO_2)	.00	1.95	.44
Water (H_2O)	2.81	8.63	5.18

The average composition of several hundred analyses from all parts of the country is as follows:*

* H. Ries, Bull. N. Y. State Museum, No. 35, pp. 639, 189.

Silica (SiO_2)	49.27
Alumina (Al_2O_3)	22.774
Ferric oxide (Fe_2O_3)	5.311
Lime (CaO)	1.513
Magnesia (MgO)	1.052
Alkalies ($Na_2O.K_2O$)	2.768
Water (H_2O)	5.749
Moisture	2.502

Clays suitable for common brick are found in many parts of the Virginia Coastal Plain area, and are worked at a number of points as described in chapter V.

Pressed brick.—These require a higher grade of clay than is necessary for common brick. At the present day those most used are buff-burning clays, of a semi-refractory character. In addition to these, red-burning clays and white-burning clays are also employed. The third class does not occur in the Virginia Coastal Plain, so far as known. Red-burning clays are by no means uncommon, and some of those now utilized for common brick could be applied to the manufacture of pressed ones. Buff-burning clays are rare; certain beds around Alexandria give a buffish product, and some of the Pleistocene clays on the lower Rappahannock river also burn buff, but the former of these only are used for face brick.

The physical requirements of a clay for pressed brick are: (1) uniformity of color in burning; (2) freedom from warping or splitting; (3) absence of soluble salts; (4) sufficient hardness and low absorption when burned at a moderate temperature. The air and fine shrinkage, as well as tensile strength, vary within the same limits as for common brick.

At the present day, buff-burning, semi-refractory or refractory clays are probably more used than any others. This is partly because their color finds favor, and partly because coloring material can be effectively added to them, for since the range of natural colors that can be produced in burning is limited, artificial coloring agents are sometimes used. Of these, manganese is the most important, and is obtainable in many localities in Virginia.

The clay must necessarily burn hard at a moderate temperature, and in the case of red-burning clays the temperature reached is usually the fusing point of cone 1 or 2. Many of the Pleistocene clays in the Coastal Plain yield an excellent hard product at this temperature. If buff-burning clays are employed it is commonly necessary to go to cone 7 or 8 to make the brick steel-hard.

A chemical analysis is of little use in judging the value of a clay for pressed-brick manufacture. It is true that the ferric oxide content will give us a clue to the color burning qualities of the clay, and a high silica content would indicate high absorption and low shrinkage, but that is all; so that a physical examination of the material is imperative.

METHODS OF MANUFACTURE.

The methods employed for making common and pressed brick are often very similar, the differences lying chiefly in the selection of the material, the degree of preparation and the amount of care taken in burning. The manufacture of bricks may be separated into the following steps: preparation, molding, drying and burning.

PREPARATION.—Many clays are put through a preliminary treatment before being mixed with water or tempered, and while clays for either pressed or common brick may go through this treatment, more care is naturally given to the preparation of clays for common brick than those for pressed brick.

Weathering.—This is a natural process of preparation. By spreading the dug clay out and leaving it exposed to the elements, it slakes down under the action of rain, and is more or less broken up by the frost. The whole mass thereby becomes more or less thoroughly disintegrated and homogenized. Iron nodules, if present, rust out, and are thus more easily seen and rejected, while pyrite, if present, may also decompose and give rise to soluble compounds, which form a white crust on the surface of the clay. The number of establishments where clays are weathered is few, and it is almost never practiced in the case of common clays. One yard at Suffolk digs its clay and leaves it exposed through the winter. Weathering clay sometimes makes up for insufficient tempering, but this should not be relied on to prepare the clay in all cases.

Dry crushing.—When hard material like shale is used, it has to go through some form of crushing machine, which will comminute it sufficiently to permit its mixing with water. The same thing has to be done if the clay is to be worked in a dry press machine, and in this case the material has to be ground, whether shale or clay.

Several types of crushing machines are used, the selection of which depends on the character of the raw material, degree of fineness required, capacity, and perhaps in some cases personal preference. The more important types used are jaw crushers, rotary crushers, rolls, and disintegrators.

Crushers.—The jaw crushers consist of two movable jaws that interact, and are set closer together at their lower than at their upper ends. One jaw is stationary, the other is pivoted at its lower end. The material to be crushed is fed into the opening between the top of the jaws and moves slowly downward, until it is fine enough to pass out between the lower edges of these.

In the rotary crushers, the machine consists essentially of a cylindrical hopper, within which there rotates a conical metal head, whose surface is corrugated, and which revolves with a gyrating motion. Of these two types of crusher, the former is more often used, and requires less power, but the latter is adapted to a wider range of material, because it is adjustable. The capacity of these crushers varies from two to two hundred tons per hour, according to the character of the shale.*

It should be remembered that these materials are applicable only to dry materials, and not wet ones.

Rolls consist of two steel cylinders, revolving at different velocities. The rolls are often adjustable, so that they can be set at varying distances apart, according to the size to which the clay is to be crushed. The differential speed of the two rolls serves not only to pull the material in between them, but also exerts a tearing action of the lumps. The surface of the rolls is either smooth-toothed or corrugated. The surface of some rolls is provided with a spiral thread, which catches large stones and carries them to the edge of the rolls where they are thrown out. Smooth conical rolls act in the same manner and are not infrequently used for preparing stony clays. In many cases the use of rolls for soft, wet clays, does not seem to prepare them very well, as the rolls simply flatten the lumps. An average size roll will prepare sufficient clay for 25,000 to 150,000 bricks per day, depending on the size of the rolls and their speed.†

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* Williams, Iowa Geological Survey, Vol. XIV, p. 165.

† Iowa Geol. Survey, Vol. XIV, p. 168.

Ring pit used for tempering clay.

Disintegrators represent a third type of machine used for breaking up clay and shale, and, where used, are commonly found to be quite effective, provided they are run on dry material. Their capacity is large, but much power is also required to drive them. A disintegrator has several drums or knives on axles, revolving rapidly within a case and in opposite directions. As the lumps of clay or shale are dropped into the machine they are thrown violently about between the drums and also strike against each other, thus pulverizing the material completely and rapidly. Such machines can pulverize from 8,000 to 28,000 pounds of material, such as shale, in one hour, and are said to require from two and one-half to four-horse power per ton per hour. Since disintegrators work best on dry material, they are commonly used in the dry-press process of brick manufacture.

Dry pans are much used for hard clays or soft shales, but they are also adapted to a wide range of materials. They consist of a circular pan in which revolve two large mullers, supported on a horizontal shaft, which may be in one piece or in two, in which case the mullers revolve independently of each other. The wheels turn because of the friction against the bottom of the pan, the latter being rotated by steam-power, and, in turning, grind by reason of their weight, which is from 2,000 to 5,000 pounds. The machine is constructed so that the mullers have some vertical play, thus permitting them to run over any lump which may not be hard enough to crush. The bottom of the pan is made of perforated removable plates, so that the material falls through as soon as it is ground fine enough, and two scrapers are placed in front of the rollers to throw the material in their path. The diameter of a dry pan ranges from 6 to 9 feet. Dry pans form a highly efficient machine, even though they are wasteful of power. Their capacity depends on the size of the screen meshes, and character of the raw material, whether hard or soft, dry or moist. For a medium shale it is possible to grind 8 tons per hour through a 1-8 inch screen, and about 12 tons through a 1-4 inch screen. Few rolls are used in the Virginia Coastal Plain area.

Ball Mills.—These form a type of machine especially adapted to fine grinding. They consist of a tube closed at both ends, and revolved by means of a suitable gearing. The charge which partly fills the tubes consists of rolled flints, and the clay to be

ground. Ball mills are not adapted to anything but high-grade clays and hence they are not discussed further here.

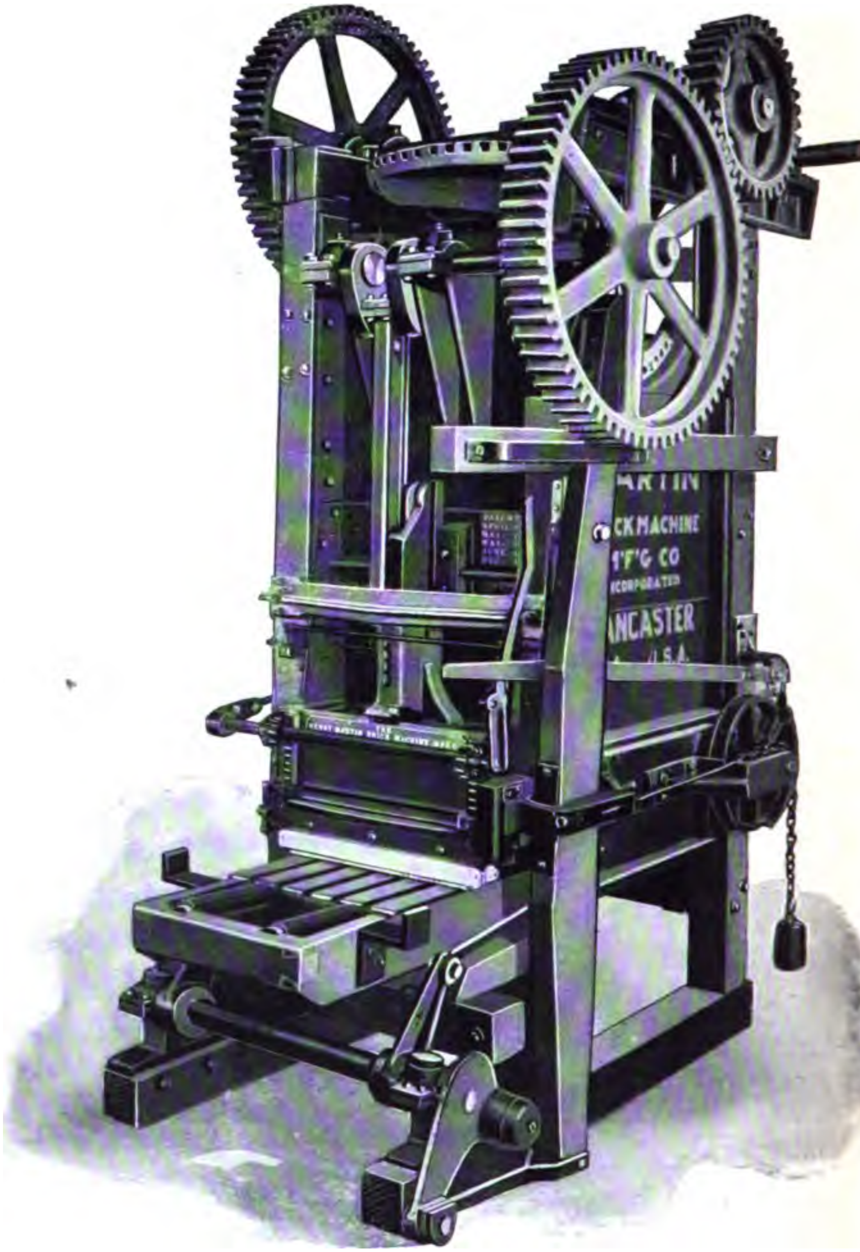
Machines for preparing wet clay.—These include soak pits, ring pits, pugmills and wet pans.

Soak pits and ring pits represent a primitive form of machine, much used at common brick yards. The former are semi-circular or rectangular pits in which the clay and water are allowed to soak over night, while the latter consists of a shallow circular pit in which the clay and water are mixed by a large iron wheel traveling around on a horizontal axis. (Pl. III.) The use of both is being slowly but surely discontinued to make room for the next type.

Pugmills.—These consist usually of semi-cylindrical troughs varying in length from 3 to 14 feet, with about 6 feet as an average. In this trough there revolves a horizontal shaft, bearing knives set spirally around it and having a variable pitch. The clay and water are changed at one end, and the blades on the shaft not only cut up the clay lumps but mix the mass, at the same time pushing it towards the discharge end. The speed of the clay through the machine varies with the angle of the blades on the shaft. Theoretically, the entire mass of clay will be mixed up by the revolving blades, but if the machine is overcharged it is not uncommon to see lumps of clay travel from one end of the trough to the other, before they are pushed through the discharge end. This can be obviated by using a closed form of pugmill, in which the clay is under pressure and the mixing action of the machine becomes more effective. The thoroughness of the mixing depends partly on the clay and partly on the length of the mill. Short ones on account of their cheapness appeal to some manufacturers, but their use should be avoided, especially in the Coastal Plain region, where the common clays used are so often of a mottled character, that it requires thorough pugging to homogenize them.

Pugmills are thorough and continuous in their action, take up less space than ring pits and do not require as much power to operate them. With a good working clay, a pugmill will, in ten hours, temper enough clay for 25,000 to 60,000 brick according to its size. They are in operation at but few yards in the Coastal Plain belt, and their use should be extended.

Wet pans represent one of the most efficient machines for preparation that the brick-maker can select, since they do both grinding



Cut of a soft-mud brick machine.

and mixing in the same operation. Structurally, they are similar to dry pans but differ from them in having a solid bottom. The material and water are put into the pan, and the clay is crushed and at the same time mixed with the water. Where the clay contains hard lumps of limonite, or pyrite nodules, a wet pan is superior to a pugmill, as these are crushed. It takes but a few minutes to temper a charge, which is then removed by a shovel, mounted on a pivoted-bearing by the side of the pan. A new charge is then added. It will be seen, therefore, that a wet pan is not continuous in its action, and its capacity is consequently smaller than that of a dry pan of corresponding size, although the amount of power required to operate it will be the same. The wet pan is not used in common brick manufacture, nor, as a rule, for those clays which are free from stones.

Screens.—When clay or shale is crushed dry, it is customary to screen it for the purpose of separating all particles that are too large and returning them to the crusher.

There are a number of different makes of screens on the market, but all belong to one of three types, namely, the inclined stationary, the inclined bumping screen, and the rotary screen of either cylindrical or polygonal section. Their qualities may perhaps be briefly summed up as follows:

Fixed inclined screens are cheap, and require few repairs, but they take up more space, are of low capacity, and, on account of their inclined position, require the material to be hoisted to their upper end so that it can be discharged on them.

Shaking screens are very efficient, and keep themselves pretty clean, so that the clay does not clog. On account of their jarring motion, however, there is more or less wear on the screen itself as well as on the building.

Rotary screens are of large capacity, especially if of polygonal section, and provided there is some means for keeping the screen cloth clean.

Screens are used in connection with the dry-press process.

MOLDING.—Bricks are molded by one of the three methods, namely, soft-mud, stiff-mud, and dry-press.

Soft-mud process.—In this method the clay is mixed to the consistency of a soft-mud and pressed into wooden molds. This originally was done by hand, and this indeed is the method still

followed at many small yards. The more modern method however consists in forming the bricks in machines driven by steam-power.

Since the clay mixture is sticky when wet, and likely to adhere to a wooden surface, the molds are sanded each time before being filled. Soft-mud bricks, therefore, show five sanded surfaces, while the sixth surface will be somewhat rough, due to the excess of clay being wiped off even with the top of the mold. They are also slightly convex on one side and slightly concave on the other, caused by the sides of the soft brick dragging slightly as it is dumped from the mold, to the drying floor.

The soft-mud machine (Pl. IV.) consists usually of an upright box of wood or iron in which there revolves a vertical shaft, bearing several blades or arms. Attached to the bottom of the shaft is a curved arm, which forces the clay into the press box. The six compartment molds after being sanded either by hand or in a sanding machine, are shoved underneath the press box from the rear side of the machine. The plunger descends in the press box and forces the clay into the mold, after which the latter is pushed forward automatically upon the delivery table, while an empty one moves into its place. The upper surface, of the mold is then "struck" off by means of an iron scraper. Under very favorable conditions soft-mud machines have a capacity of about 40,000 bricks per ten hours, but most of them rarely exceed 25,000.

The soft-mud process is adapted to a wide range of clays, and produces a brick of very homogeneous structure, which is rarely disintegrated by frost. Since the pressure applied to the brick is not as great as that given to it in other methods of molding, the product is somewhat porous. This, however, tends toward the development of brighter colors, since the iron in the clay is more easily oxidized during burning.

The cost of the soft-mud process is small, but its capacity is limited as compared with a good stiff-mud machine, and for the same capacity a larger number of men are required to operate it.

The soft-mud machine does not produce a product with smooth faces or sharp edges, but this defect can be overcome by repressing the product, and where the bricks are to be used for fronts this is often necessary.

Curiously enough many of the Coastal Plain yards of Virginia still adhere to the hand method of molding.

A stiff-mud brick machine; shows bar of clay issuing from die.

Stiff-mud process.—In this method of molding the clay is tempered with less water, and is consequently much stiffer. The principle of the process consists in taking the clay thus prepared and forcing it through a rectangular die in the form of a bar which is then cut up into bricks. The machine now most used is known as the auger type. (Pls. V, VI, and VII.) This consists of either a vertical or horizontal (usually the latter) pugging chamber from which the clay passes to the die, and is forced out through the latter by means of an auger. The internal shape of the die is variable, depending on the make of the machine, and is heated by steam or lubricated by oil on its inner side in order to facilitate the flow of the clay through it.

The tempered clay is charged into the cylinder at the end farthest from the die, is mixed up by the revolving blades, and at the same time moved forward until it is seized by the auger and forced through the die. Since this involves considerable power it results in a marked compression of the clay. One serious fault of the stiff-mud machine is its tendency to produce a laminated structure in the bar of clay. This is due partly to the action of the auger, which acts to twist the clay into a series of concentric layers, that slip over each other producing a slickened surface. This laminated structure is still further emphasized by the friction between the sides of the die and the surface of the clay bar, which causes its central portion to move faster than the outer part.

The laminated structure is greatest in highly plastic clays, but with proper pugging and lubricating it can be often decreased, and machine manufacturers have spent much time endeavoring to perfect a die and auger which will give smooth results. Lubrication of the die also serves the purpose of preventing serrations on the edges of the bar. Neither very sandy nor highly plastic clays yield good results in an auger machine.

Laminations are undesirable, as they weaken the brick, but are more harmful in pavers than in common building brick; their effect is probably lessened by harder burning.

Some machines are provided with a sand box, which sands the bar of clay as it issues from the die, the object of the sand being to prevent the bricks sticking together in burning, or improve their color, and incidentally to aid in handling. The brick made in auger machines are either end cut or side cut, depending on

whether the area of the cross-section of the bar of clay corresponds to the end or side of a brick.

The auger machine has a large capacity, and can produce 45,000 or even 60,000 bricks in ten hours, the output of the machine being sometimes increased by the use of a double or even triple die, but this is not a desirable practice. A machine making eight to ten thousand brick per hour requires seventy to seventy-five horsepower.*

As the bar of clay comes from the machine it passes on to the cutting table, of which there are several different types, the cutting apparatus being operated either by hand or automatically, but the cutting is in every case done by wires, which are drawn across the bar. These wires have to be as thin as possible and yet be strong; they must make a small clean cut in a downward direction. Strong and thin as they are they nevertheless are easily broken by striking on stones, roots or hard lumps, within the bar of clay. In some cutters the wires are fastened with springs so that there may be some give to them in case they meet with an obstruction in cutting the clay. Some cutters are also provided with automatic wire cleaners.

Cutting machines are of two classes, namely, those in which the cutting wires move at right angles to the bar, and those in which the wires revolve in the same direction in which the clay moves.

Those of the former type are so designed that the wires are drawn either straight through it from one side to the other, or else they cut through it with a partially rotary motion. A cutter of this type may be operated by hand or automatically. In the latter type, there are a number of short wires, each borne on a fork-like frame at the end of a series of arms corresponding to the spokes of a wheel. This cutter revolves as the bar of clay issues from the die, so that each wire as it descends cuts through the bar.

Any of the several types of cutting machines mentioned can be used for either end-cut or side-cut bricks, and although there are many different makes of cutting tables on the market it is doubtful whether any possess special advantages over the others.

The stiff-mud process is adapted mainly to clays of moderate plasticity, and does not work well with stony clays, unless the stones

* Iowa Geol Survey, Vol. XIV, p. 195.

are previously removed, for the cutting wires are likely to be broken by contact with them, which necessitates a frequent stoppage of the machine for repairs. While these do not take long to make, still delays of any kind are expensive. Stiff-mud brick, like soft-mud ones, can be repressed, and many face brick are now made by this method.

The stiff-mud process is a good one, if properly used, but the clays should be thoroughly tempered before molding.

Repressing.—Many soft-mud and stiff-mud brick, that are to be used for fronts or pavers, are repressed for the purpose of giving them greater density, straightening the edges and smoothing the surfaces. The repressing of stiff-mud brick can be done as soon as they are molded, or after they have been hacked for several hours. Soft-mud brick have to be dried somewhat before being sent to the repress.

The repress consists essentially of a steel mold box, into which the molded brick is dropped automatically and pressure applied from above or below or both, by means of plungers. The pressure is applied gradually until it reaches its maximum, or else the brick may be given two distinct pressures, with a slight interval of relief between. The latter probably yields the best results. The amount of pressure varies, and in the strongest machines a maximum of 45,000 pounds per square inch can be attained,* but the amount of pressure given to the brick can be regulated.

Since the brick does not fit perfectly into the mold, it will undergo a slight change of dimensions in repressing, which involves increase in length and width and decrease in thickness; the cubic volume will, however, be less after repressing than before. A certain amount of flow thus takes place in the mass, resulting naturally in something of a change in structure. There has been much discussion regarding the advantages of repressing, and the possibly injurious effects.

If a brick fits tightly into the press box of the repress, practically no change of structure takes place in repressing; if there is some room for a flow of the mass the original structure may be partly destroyed; or, if the brick fits loosely, the flow in the mass may be sufficient to produce an entirely new structure.

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* Iowa Geol. Survey, Vol. XIV, p. 204.

Since the action of most represses agree most nearly to the second of the three cases mentioned, it would seem doubtful whether repressing could be looked upon as desirable treatment.

Some years ago the National Brick Manufacturers Association appointed a committee to investigate this subject and determine, if possible, whether repressing always increased the strength of a brick. After making a long series of experiments on both end cut and side cut brick, they found that in most cases, repressing injures the wearing qualities of the brick. Following this was a series of experiments to determine the influence of flow in the repress die, in which they used dies permitting a varying degree of flow in the mass during repressing. Their conclusions were, that it is best to assume that plain wire cut bricks are superior to repressed ones, until it can be proved that in any case the reverse holds true.

Repressing is at times necessary in order to meet local requirements, or market conditions, in which case it should be of such character as to completely destroy the auger machine structure, and develop an entirely new one. Under such conditions the brick may often be improved.

Repressed bricks often have a very smooth surface, caused in part by the rubbing of the clay against the sides of the die, and in part by the liberal use of oil, which tends to facilitate the delivery of the brick from the press box. The operation of repressing may also serve to form a skin which is denser than the interior of the brick and thus protect it against the weathering. If stiff-mud bricks are to be used for fronts it is often desirable to repress them because many irregularities of surface caused by the cutting wires are thus reduced.

Dry-press process.—In this method of molding, the clay is used in a nearly dry condition, that is it may contain perhaps 15 per cent. of moisture. The clay is first pulverized in some form of pulverizer or dry pan, screened to from 12 to 16 mesh, and then delivered to the machine. Before describing the latter, it may be well to refer to the methods of preparation used. If plastic clays are chosen these are often too moist when first dug and are stored up under a shed for the purpose of drying out as well as disintegrating them. Shales, too, are often stored up in piles in order to allow them to mellow somewhat. Disintegrators seem

often to pulverize the raw material more finely than a dry pan, and if the clay or shale is not ground fine enough, or not properly screened, it does not add to the appearance of the brick. Improper grinding yields coarse particles which give the brick a coarsely granular structure. Sandy clays do not always work well in a dry-press machine.

The molding machine consists of a steel frame of varying height and weight, with the delivery table about three feet above the ground, and a press box sunk into the rear of it. The charger is connected with the clay hopper by means of a canvas tube, and consists of a frame work which slides back and forth over the molds. It is filled on the backward stroke, and on its forward stroke allows the clay to fall into the mold box. As the charger recedes to be refilled, a plunger descends, pressing the clay into the mold.

The clay in most dry-press machines is subjected to several maximum pressures, the relief between pressures being for the purpose of allowing the air imprisoned in the clay by compression to escape through holes in the die. Were this not done, the expansion of the compressed air, following release of pressure, would burst the brick. After the clay has received its pressure in the mold, the upper plunger, and also the lower one (which forms the bottom of the mold box), ascend, until the molded bricks reach the level of the delivery table, when they are pushed forward by the charger as it advances to refill the molds. The mold is of hard steel and heated by steam to prevent adherence of the clay. The pressure necessary to form the clay is generally applied by means of a toggle joint, and four or six bricks are usually molded at a time according to the size of the machine. A four mold press will make about 20,000 bricks per day, and a six mold press about 30,000.

The advantages claimed for the dry-press process are, that in one operation it produces a brick with sharp edges and smooth faces. There is little water to be driven off, hence no drying apparatus is necessary. The process itself is probably the cheapest that there is for molding brick, although the initial cost of the plant is somewhat high. If properly burned the bricks are as strong and durable as those made by any other process.

The dry-press process is adapted to quite a wide range of clays, and although the plastic qualities of the clay do not play any

role, still the more plastic clays seem to cohere better when dry.

Practically all of the clays produced in the Coastal Plain region of Virginia could be used for the manufacture of dry press brick, and yet there is but one machine of this type in operation in the entire area.

DRYING.—The primary object of drying clays is to free them of water added during tempering, and also the water which they originally held in their pores, although the latter is expelled with difficulty.

This water is removed by exposing the bricks to an atmosphere of hot air. In natural drying this is supplied by the sun: in artificial drying, it is generated with some form of fuel. As the water in the clays is warmed it begins to evaporate, forming watery vapor, and unless this is removed from around the brick. and fresh, dry air allowed to take its place, drying is retarded. Consequently, the air in which the bricks are drying, should be in motion. In open-air drying the wind aids this; in chamber or tunnel drying, the hot air passing up the chimney draws in a fresh supply of drier air behind it. Now while lack of motion in the air surrounding drying brick may retard evaporation, so, too, an excess of air current may accelerate it and indeed to such an extent as to make the brick shrink too fast and consequently crack.

Or, if, on the other hand, the brick is heated too rapidly, the water within the pores may be converted into steam, which, in its efforts to escape, splits the ware.

Bricks made by either the soft-mud or stiff-mud process have to be freed of most of their moisture before they can be burned. This is done by drying them in, (1) open yards; (2) on covered yards; (3) on pallet racks; (4) in tunnel dryers; or, (5) on floors.

In the open yards the bricks are set on the ground and dried by the heat of the sun; the same is the case on covered yards which differ only from the former in having a sectional roof which can be lifted up in stormy weather and closed in rainy weather. With the pallet system the bricks are set on racks, protected by a roof, and while not exposed to the direct rays of the sun are dried by its warmth. All these methods are essentially open air methods, one or the other of which is usually employed at common brick yards. Indeed it is very improbable that any of these will ever

go entirely out of use, to make way for artificial dryers. While cheaply operated, they possess many disadvantages. They are dependent on the weather, and bricks cannot dry in wet, stormy weather, neither can this system of drying be operated in winter. Drying proceeds very irregularly, fast one day and slow the next, according to the meteorologic conditions. In windy weather many tender clays have to be carefully protected, to prevent rapid drying and cracking.

They also occupy considerable space. It is possible to construct the roofed yards, referred to above, with steam coils under the floors, and utilize exhaust heat from the engine, thus greatly increasing their efficiency.

Tunnel dryers represent a drying system much used in brick plants at the present day, and is probably the most economical means there is.

They consist essentially of a series of parallel tunnels of brick or wood, heated either by hot air passing through them, or by heat radiated from steam pipes on the surface of brick flues. The heat passes in at one end, and out through a stack at the other, which is the cooler. The cars containing the green brick are pushed in at the cooler end, slowly traverse the tunnel and emerge at the other, so that while in use the tunnel is filled with cars of brick. Each time a car is pushed in at the cool end one is drawn out at the other end.

The action of the tunnel dryer is somewhat as follows: The hot air which enters the tunnel is moderately dry, but as it comes in contact with the brick in its passage towards the stack, it becomes loaded with moisture from the brick, so that when it gets to the chimney it is very close to saturation. The bricks entering the stack end come at once in contact with a hot moist atmosphere, which tends to warm them up, but permits of little drying, for the water in them will not pass off into an atmosphere which is already saturated with it. Consequently, the bricks at first become warmed up. As they move slowly towards the less humid air of the middle section of the tunnel they begin to lose some of their moisture and shrink; finally, when they reach the hot end the shrinkage has ceased but most of the remaining moisture is driven from their pores.

All clays cannot be dried with equal rapidity; indeed, some have to be dried very slowly in order to prevent checking. This is accomplished partly by moving them very slowly through the dryer and partly by diminishing the air current in the end, at which the brick enter. The latter is accomplished in some dryers by carrying off the hot air before it reaches the end of the drying tunnel, thus decreasing the circulation of the air at the entrance end of the tunnel.

Drying tunnels are heated in several different ways. The one most commonly adopted is to heat the interior of the tunnel by radiation from steam coils, which are arranged along the sides, or bottom or both. The coils are supplied by either live or exhaust steam, the former by day, the latter by night, or sometimes in the daytime as well. Some persons advocate live steam, while others prefer the exhaust. It seems probable however that the latter is the more desirable from the standpoint of economy, since we are utilizing a waste product.

Steam heating, whatever kind of steam be used, is probably the most desirable method, since it is efficient; there is little risk from fire due to overheating, and, moreover, the heat can be easily distributed from the point at which it is generated.

A modification of this type consists in having the steam pipes outside the dryer in a chamber by themselves, and by means of a fan draw the air over them before conducting it to the dryer.

According to Richardson* the advantages of this form of dryer are: 1. Less pipe required; 2. Greater economy of steam; 3. Better circulation in dryer and hence more rapid drying; 4. Convenience of making repairs to steam pipes; and 5. This system permits of the use of waste heat from cooling kilns without any change other than the adjusting of dampers.

In another type of dryer the heat is generated in a fireplace and conducted through brick flues which extend under the dryer floor, the heat being thus radiated through the flue walls. The gases pass from the flues into the same stack which draws the heated air from the dryer, and thus aid the draft in it. Such dryers are not adapted to tender clays, and while their cost of maintenance is low they are exceedingly wasteful of heat.†

*Clay-Worker, XLIV, p. 342.
†Iowa Geol. Survey, Vol. XIV, p. 258.

In both the foregoing types the bricks are heated by radiation from hot surfaces. There are other kinds of dryers in which the hot air is conducted directly into the tunnel, and comes in contact with the bricks. This heated air may be supplied by fuel burned for the purpose, or else by the waste gases from the kilns. In the former there is danger of the ware becoming coated with soot or a scum unless the combustion of fuel supplying the heat is perfect. The scum owes its formation to sulphuric acid from the combustion gases settling on the moist hot brick in the dryer attacking some compounds, such as carbonate of lime, and converting them into sulphates which remain as a whitish coating on the surface of the ware. Fans are often used to aid the draft.

Dryers heated by waste gases from cooling kilns are not yet extensively used in this country, although they possess many excellent points. With this method the heat from the cooling kiln is carried through pipes into the dryer. Since this air is usually much hotter than desired it is necessary to mix some cold air with it. At the same time the air must not be allowed to cool down to its dew point, as it would deposit moisture on the bricks.

The advantages of this system are that a waste product is being used as a source of the heat, while among the disadvantages are the cost of piping the hot air, and the great care needed to maintain the hot air at a constant temperature.

Some large plants in the United States are using the process with excellent results.

There are other drying methods such as slatted floors heated by steam coils, and brick floors warmed by hot air flues beneath them, but they are not used in the drying of building brick, and hence are not mentioned here.

BURNING.—This stage of the process of manufacture is an important one, and although the clay may have passed safely through the preceding stages, much loss may occur at this very point. The imperfect bricks thus obtained may be due (1) to mistakes of the burner; (2) to the clay; (3) to the fuel; and (4) to the construction of the kiln. In burning, certain changes, partly physical and partly chemical, take place in all clays, as the result of which the brick is converted into a solid mass, which is hard and rock-like when cool. Other changes, due to the presence of certain ingredients or certain physical characteristics of the clay, occur in specific cases.

The amount of heat required for burning brick will vary with the clay; and the color, density and degree of hardness desired; the same clay giving different results, when burned at different temperatures. Common brick are rarely burned higher than cone 05 or 03, while pressed brick are frequently fired to cone 7 or 8, because the clays generally used have to be burned to that point to render them hard.

General effects.—In burning, the last traces of moisture are driven off. The chemically combined water is also expelled, most of it passing off at a very dull red heat. Its expulsion is shown by the steam (water smoke) issuing from the kiln and results in a slight loss of weight. If the bricks are set too wet, rapid heating causes much split or popped ware, due to the steam passing off too violently. This applies to mechanical and not chemical water. A good draft aids the evaporation of the water in the clay. A poor draft may cause moisture to condense on the surface of the ware and produce scumming.

If the clay contains considerable carbonaceous matter, this will burn off at a low heat, provided in the first place sufficient air is present to insure an oxidizing atmosphere. In this case carbon in the clay uniting with the oxygen of the kiln atmosphere burns off as carbon dioxide. If the heat is raised too rapidly the clay contracts before all the carbonaceous matter is burned off, and the result is a black centre to the brick, which may also be accompanied by a swelling of the clay. In calcareous clays the carbonate of lime present also loses its carbon dioxide. The driving off of all these substances will, therefore, tend to make the brick very porous. Further heating, however, after volatilization of these substances, causes a drawing together of the clay particles, or shrinkage, and this is accompanied by an increase in density and hardness—the maximum density and shrinkage being reached when the brick is vitrified.

The effects of heating a clay may be summarized as follows:

1. Loss of volatile substances present, such as water, carbon dioxide and sulphur trioxide, the volatilization of these leaving the clay more or less porous.

2. A shrinkage of the mass by further heating.

3. Hardening of the clay due to fusion of some, at least, of the particles.

Cutting table of stiff-mud brick machine; shows revolving cutter, and the cut brick coming from cutting table.

4. Increasing density with rising temperature, the maximum being reached at the vitrifying point of the clay.

Effects due to variation in the clay.—Burned clays may be of many different colors. Although the majority of clays contain sufficient iron oxide to burn red, nevertheless it is not safe to predict from the color of the clay, the shade that it will burn, since some bright red or yellow clays may yield a buff brick. If considerable iron oxide is present, 4 to 5 per cent., the brick burns red, provided the iron is evenly distributed, unless much lime is also present. If only 2 to 3 per cent. are present, a buff product is obtained, whereas, with 1 per cent. or under, the clay burns white, or nearly so. An excess of lime in the clay will, however, counteract the effect of the iron oxide and yield a buff brick, but a brick owing its buff color to this cause will not stand as much fire as one which owes its buff color simply to a low percentage of iron oxide.

When a clay is mottled a red and white, for instance, the colors of the different spots will retain their individuality most plainly after burning, unless the clay is thoroughly mixed. Some Virginia clays contain lumps of bluish white clay, much tougher than the rest of the mass. These resist disintegration in the tempering machines, so that after burning they can be plainly seen as buff spots in the red ground of the brick.

The normal iron coloration may often be destroyed by the effects of the fire gases. When these are reducing in their action. i. e., taking a part of the oxygen from the ferric compounds and reducing them to ferrous compounds, the red color may be converted to gray, or even bluish black, if the reduction is sufficient, so that in some districts the bricks, on account of lack of air in the kilns and carbonaceous matter in the clay, do not burn a very bright red. Moreover, other things being equal, the higher the temperature at which a clay is burned, the deeper will be its color.

The surface coloration of a burned brick may often be different from the interior. This is due to several causes. (1) Soluble salts may accumulate on the surface, sometimes causing a white coating, because they have been drawn out by the evaporation of the water during the drying of the brick. (2) The deposition of foreign substances by the fire gases may cause a colored glaze.

This is especially seen on the ends of arch brick, and on the bag walls of a down-draft kiln, where the particles of ash carried up from the fires stick to the surface of the hot brick and cause a fluxing action. (3) If the clay contains much lime carbonate, and there is much sulphur in the coal, the latter may unite with the lime, forming sulphate of lime, and thereby prevent the combination of the lime and iron. In this case the centre of the brick, not being thus affected by the gases, may show a buff color, whereas the outside has a different tint.

Flashing.—Many bricks used for fronts are often darkened on the edges by special treatment in firing, caused chiefly by setting them so that the surfaces to be flashed are exposed to reducing conditions, either at the end of the firing or during the entire period of burning. This color is superficial and may range from a light gold to a rich, reddish brown. The principle of the operation depends on the formation of ferrous silicate and ferrous oxide, and their subsequent partial oxidation to the red or ferric form. This oxidation probably takes place during cooling, for if the kiln be closed so as to shut off the supply of oxygen, the brick are found to be a light grayish tint.

The degree of flashing is affected, (1) by the composition and physical condition of the clay; (2) the temperature of burning; (3) the degree of reduction; and (4) the rate of cooling and the amount of air then admitted to the kiln.

1. The percentage of iron oxide should not be large enough to make the brick burn red but to produce buff coloration, and the clay should have sufficient fluxes to reduce the point of vitrification to within reasonable limits, thus facilitating the flashing. Clays high in silica are apparently better adapted to flashing than those low in silica and high in alumina. The condition in which the iron is present in the clay probably exerts some influence, that is, whether it is there as ferric oxide, ferrous silicate, concretionary iron, ferrous sulphide, or perhaps ferrous carbonate. Bleininger's experiments showed that of three clays used for flashing, all contained considerable quantities of iron soluble in acid. Some eastern manufacturers are obliged to add magnetite ores to their clays, which are low in combined iron, and No. 2 fire clays, which contain more iron than the finer grades, seem to give the best results. As to the effect of the physical condition of the clay, fine grinding

seems to give more uniform flashing effects, and the reason that stiff-mud bricks flash better than dry-press ones is claimed by some to be due to vitrification taking place more easily in the former.

The following analysis gives the composition of a No. 2 fire clay from Ohio used for flash brick:

ANALYSIS OF AN OHIO NO. 2 FIRE CLAY.

Silica (SiO_2)	67.14
Alumina (Al_2O_3)	19.74
Ferric oxide (Fe_2O_3)	2.46
Lime (CaO)	0.53
Magnesia (MgO)	0.71
Potash (K_2O)	2.80
Soda (Na_2O)	0.43
Water (H_2O)	7.01
Total	100.82

In one case the green clay showed a total of 2.15 per cent. of ferric oxide, of which 0.88 per cent. was soluble in acid. The flashed surface of a brick made from this clay gave, on analysis, a total of 2.31 per cent. of ferric oxide, of which 0.14 per cent. was soluble in nitro-hydrochloric acid, thus indicating that during the burning most of the iron oxide had combined with silica, forming a ferrous silicate.

2. The temperature reached must be sufficient to cause a combination of the iron and silica, and, therefore, it varies with different clays, the combination being aided by the presence of fluxes.

If the kiln atmosphere is oxidizing during nearly the entire burning, with only a small period of reduction at the end, the temperature reached must be comparatively high, in order to insure union of the iron and silica by fusion. If, however, a reducing fire is maintained during most of the burning, then the temperature need not be as high, because the clay will vitrify sooner.

At one factory it had formerly been the practice to burn with an oxidizing fire to a high temperature, namely, from cone 11-12, and then to cause reducing conditions to take place in the kiln during the last 5 or 6 hours of the burn. This practice, however, was changed, it being found that by maintaining a reducing fire during the entire period following water smoking, a lower temperature was sufficient.

3. The oxidation which causes the flashing probably takes place in the first twelve hours after closing the kiln, and can be regulated by a proper handling of the dampers.

In the experiments of Bleininger already referred to, it was found that a reduction of air, equal to 20 per cent. below that required for ideal oxidation, and considered as 100, is usually sufficient to produce flashing.

By this is meant that "100 per cent. of air represents, theoretically, ideal conditions, in which just enough air is present to consume all the combustible gases forming CO_2; less than 100 per cent. of air corresponds to reducing conditions. For instance, if an analysis on calculation represents 90 per cent. of air, it tells us that the gases are reducing to the extent of 10 per cent. of air; similarly 100 per cent. shows an excess of air to the amount of 10 per cent."

While 100 per cent. represents, theoretically, the amount of air required for perfect combustion, still in actual practice with coal fuel the mixture of gases is not perfect, and it may be necessary to have more than 100 per cent. of air present to bring about thorough oxidation.

4. As regards the rate of cooling, it was found that the longer the period of cooling from the maximum temperature down to approximately 700°C., the darker the flash under given conditions.

KILNS.—Bricks are burned in a variety of kilns, ranging from temporary structures, which are torn down after each lot of brick is burned, to patented or other permanent forms of complicated design. They are built on one or two principles, either up-draft or down-draft.

Up-draft kilns.—In these the heat from the fire boxes at the bottom passes directly into the body of the kiln and up through the wares, escaping from suitable chimneys or openings at the top.

The simplest type of up-draft kiln is known as the scove-kiln, which is in use at many yards where common brick are made. With this method the bricks are set up in a large rectangular mass, from 36 to 42 courses high (in Virginia), while at the base a series of parallel arch-like openings is left extending through the pile. The bricks are surrounded by a wall two bricks thick, of green brick or underburned ones, and the exterior daubed over with wet clay to exclude cold air during burning. The top of the mass is closed by a layer of bricks laid flatwise, and termed the platting. The fuel is placed in the arches, and the heat ascends through the kiln and passes out at the top. Such kilns are adapted only to

the manufacture of common brick. They are wasteful of heat, difficult to regulate and require considerable skill. Moreover, the walls have to be torn down and rebuilt each time a new lot of bricks is burned. Then, too, the percentage of poor bricks is often large.

A step in advance of the scove-kiln is the up-draft kiln with permanent side, and partial end walls, and sometimes even a furnace for burning the fuel, instead of putting it in the arches. (Pl. VIII, Fig. 2.). It is this type of kiln which is most used in the Coastal Plain region. Such kilns can be better regulated, and there is less loss of heat and product. Another step further are those up-draft kilns, constructed with both walls, and roof permanent, the products of combustion escaping through a series of small chimneys at the top of the kiln. Such kilns are either rectangular or circular in plan.

Down-draft kilns.—In these the heat from the fires is conducted first to the top of the kiln chamber by means of suitable flues, on the inner wall of the kiln, and then down through the ware, being carried off through flues in the bottom of the kiln to the stack. The down-draft system of burning is growing in favor, as the operation can be regulated better, and there is less loss from cracked or overburned brick. Furthermore, since the bricks at the top receive the greatest heat, and those at the bottom the least, there is less danger of the bricks in the lower courses being crushed out of shape. There are many different types of down-draft kilns, most of which are patented, but they differ chiefly in the number and arrangement of the flues leading from the kiln chamber to the stacks, and in the shape and number of stacks as well. In the construction of such kilns it is essential to see that they are so built as to distribute the gases as evenly as possible throughout the kiln, otherwise irregular burning results.

If this is not looked after, the gases will, after entering the kiln chambers, attempt to take a short cut to the flues nearest to the stack. Where the kiln shows a tendency to act in this manner an effort is sometimes made to remedy it by setting the ware close in that portion which the gases follow too freely, so as to divert some of them at least into those parts of the kiln which do not receive enough heat. This tendency on the part of the gases to follow

the shortest route would be common in a circular kiln, with a center draft and one outside stack. The best results, and the most uniform heat are obtained by taking the gases off through a number of channels in the bottom of the kiln. The arrangement and size of these channels is variable, but the best results are obtained when with a central outlet, the flues nearest this are of smaller area than those farthest from it, the object of this being to counteract any tendency for the gases to follow the most direct path. But even if the kiln has a perfect draft, setting may to some extent interfere with this.

The bottom of a down-draft kiln is rarely as hot as the top, due partly to the gases cooling somewhat in their passage through the kiln. To overcome this, the draft may be accelerated, so as to draw the gases through the kiln as quickly as possible. A common means of accomplishing this is to have a false work or bottom of flues, under which there is a free space for the gases to move freely before entering the stack, the large volume of gas moving in this underspace tending to overcome the retardation caused by the gases passing through the set ware.

Down-draft kilns are either circular or rectangular in form, the former having a capacity of 25 to 60 thousand, and the latter from 150 to 200 thousand. The rectangular are more economical of space, and are the type commonly used for burning brick, while the circular ones are preferred for drain tile, sewer pipe, or stoneware.

Rectangular down-draft kilns are often operated with one stack, located either at the end or side, the latter being preferable as it promotes a more uniform draft. In the circular kiln, a center stack gives the best results, even though it may take up some space in the interior of the kiln.

These kilns naturally require skill and intelligence to insure their proper workings, and must also be kept in proper repair, as well as having dry foundations to insure continuously good results.

In addition to finding considerable structural variation in the interior of the kiln, the style of fireplace or mode of firing varies. This may be done on flat grate bars, inclined grate bars, or dead bottom.

Stiff-mud brick machine and revolving cut-off for making side-cut brick.

Of these, the flat or horizontal grate bar is the more often used, the fuel being placed on this and the air for combustion passing up through it. Firing by this method requires care, so as not to allow of too much air passing through the fuel, but the method permits higher efficiency. Overfeeding the fires results in smoke, and means loss of heating elements.

In some furnaces, styled coking furnaces, the grate has a plate of sheet iron or fire brick set in front of it, and on which the fresh fuel is placed before it goes into that portion of the fireplace where it is burned. In this position it gets preheated by the coal on the grates and is thereby warmed enough to drive off its volatile hydrocarbons, which are drawn in over the fire, where they are burned. If this same fuel were put directly on the fire, these gases would pass off in large part without being consumed. When the gases have been driven off, the coked coal is pushed onto the grate, where it is burned.

Inclined grate bars are set in a slanting position, reaching from the front of the furnace, part way towards the rear. In starting the fire, the fuel is heaped up at the rear of the furnace, and as coal is added the fire gradually builds up on the grate bars. The air for combustion passes in over the fuel and through it. There is less danger of an inrush of cold air into the kiln by this method of firing, but danger from gases passing into the kiln during cooling, for the fuel on the grates burns for some time after the firing is stopped. If the coal contains much sulphur this is liable to cause discoloration of the ware.

Dead-bottom firing is done without the use of grate bars, but the furnace is somewhat differently constructed, having an upper and lower opening in front. The fire is started in the lower part of the furnace or ash pit, and fuel gradually added, so that the mass reaches to the upper door, the top of the fuel being inclined. Owing to the necessity for cleaning out the fires from time to time, the supply of air is irregular, or, in other words, may alternate between reducing and oxidizing conditions. This is not favorable to the development of uniformity of color in the ware. This method is, however, a cheap one, and adapted to any grade of coal of the proper clinkering qualities.

Continuous kilns.—These were originally designed to utilize the waste heat from burning, and although the kiln has been con-

structed in several different forms, the principle of them all is the same. The kiln consists of a series of chambers, arranged in a line, circle, oval or rectangle, and connected with each other and with a central stack by means of flues. The object of this is to utilize the waste heat from the cooling ware, by drawing it through chambers of cooling ware, which are thus warmed by heat that would otherwise go to waste.

The chambers are separated by brick walls or temporary walls of thick paper, and each chamber holds about 20,000 brick. In starting the kiln, a chamber full of bricks is first fired by means of exterior fire boxes, and while the water smoke is passing off, the vapors are conducted to the stack, but as soon as this ceases the heat from the chamber first fired is conducted through several other chambers ahead of it, before it finally passes to the stack. In this manner the waste heat from any chamber is used to heat the others. When any one compartment becomes red hot, fuel in the form of coal slack is added through small openings in the roof, which are covered by iron caps.

As soon as one chamber has reached its highest temperature, the two or three chambers ahead of it are being heated up while those behind it are cooling down. A wave of maximum temperature is therefore continually passing around the kiln. It is thus possible to be burning brick in certain chambers, filling others, and emptying still others all at the same time. The distance ahead of the fire which the gases may be carried depends on the point at which they are nearly saturated with moisture. If carried farther they begin to deposit moisture on the ware instead of taking it from it. A strong draft is of great importance, as the gases have to travel a much longer distance than they do in other types of kilns.

Continuous kilns are not used nearly as much in this country as abroad, although there seems no reason why they should not be, but it has been suggested that greater care in the construction and operation is necessary in order to insure uniform success.

PAVING BRICK.

Many different kinds of clay are utilized in the manufacture of paving brick, although shales perhaps are most favored. None of these occur in the Coastal Plain of Virginia, but they are not uncommon in the western part of the State. Some of the reasons

why shales are found to be so well adapted for the manufacture of paving brick are, that they are so fine grained, and because they often contain the proper quantity of fusible impurities. These two characteristics permit the shale to fuse to a homogeneous mass at a comparatively low temperature. Paving brick materials vary considerably in their composition, but the range shown by 25 selected samples is given below.*

Components	Minimum	Maximum	Average
Silica (SiO_2)	49.00	75.00	56.00
Alumina (Al_2O_3)	11.00	25.00	22.50
Ferric oxide (Fe_2O_3)	2.00	9.00	6.70
Lime (CaO)	.20	3.50	1.20
Magnesia (MgO)	.10	3.00	1.40
Alkalies (Na_2O, K_2O)	1.00	5.50	3.70
Ignition	3.00	13.00	7.00

These analyses indicate a somewhat high percentage of iron oxide, lime, magnesia, and alkalies.

Clays used for making paving brick should possess at least fair plasticity since they are commonly molded by the stiff-mud process; and they should vitrify at a comparatively low temperature. The methods of manufacture are essentially the same as those described under building brick.

DRAIN TILE.

The clays employed for the manufacture of drain tile are very similar to those used for building brick, care being often taken, however, to use materials as free from grit as possible. They are tempered in the same manner as brick clays and molded in a stiff-mud auger machine, which differs only from that used for brick, in the style of the die.

Drain tile are commonly dried on pallet racks, although at some yards drying floors are employed. They are burned either in a kiln by themselves, or set in with the bricks, in case both are made at the same yard, and are to be burned at the same temperature.

Although a few manufacturers burn their tile to vitrification, the majority are not burned any harder than common brick, so that the temperature ranges usually from cone 010 to cone 05. This is generaly sufficient, as the tile do not have to bear any pressure when in use. Being set in the soil, they are subject only to the action of frost.

*Wheeler, Missouri Geological Survey, Vol. XI, p. 456.

HOLLOW WARE FOR STRUCTURAL WORK.

Under this title are included fire-proofing, terra-cotta lumber. hollow blocks and hollow bricks. They resemble each other in being hollow, frequently of rectangular outline, and are strengthened by one or more cross-webs or partitions.

Fireproofing applies to those shapes used in the construction of floor arches, partitions and wall furring for columns, girders, and other purposes in fireproof buildings.

Terra-cotta lumber is a form of fireproofing that is soft and porous, owing to the addition of a large percentage of sawdust to the clay. The former burns out in the kiln, thus leaving the material so soft and porous that nails can be driven in it. It is used chiefly for partitions.

Hollow blocks are used for exterior walls in both fireproof and non-fireproof buildings.

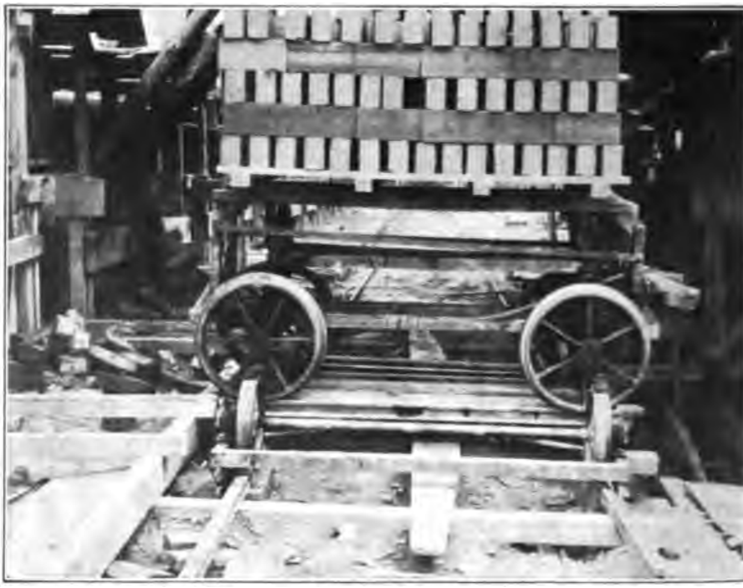
Hollow brick are like hollow blocks in form, but little or no larger than ordinary building bricks.

A number of different shapes and sizes of fireproofing are made, and while the majority of them agree in being 12 inches long, the other two dimensions may vary. Thus, of the blocks which are 12 in. long, the other two dimensions may be 6 by 3 in., 6 by 4 in., 6 by 5 in., 6 by 6 in., etc. Many different fire-proof shapes made are for floor arches, and in such cases the architect commonly specifies the depth of the arch, while the width of the blocks is governed by the width of the span.

Hollow blocks are usually made in 8 inch lengths, but vary in the other two dimensions, being 4 by 16, 6 by 16, 8 by 16, etc. They are used extensively in the Central States, but not so much in the eastern ones. It is probable that the more plastic Coastal Plain clays of Virginia could be used for this purpose.

The method of preparation and molding is essentially the same as that employed in making stiff-mud brick. The die of course is of special type, which emits a hollow tube with cross partitions. The cutting table is likewise of a specialized type, and so designed that as the brick reaches the end of the table it is turned to an upright position to facilitate handling.

Owing to the peculiar structure of the die, the clays used must flow through it easily, and after burning yield a body sufficiently



A. Car of green bricks. These are wheeled to the drying shed, where the platform with bricks is set on supports, and the trucks taken back to the molding machine for another load.

B. Up-draft kiln, with permanent side-walls but no roof. Much used in the Coastal Plain area for burning common brick.

hard and strong to bear the necessary weight when set in a wall.

Williams gives the following advantages for hollow blocks:*

Lightness.—Sufficient strength to insure a large factor of safety in any common building construction. Amount of clay required, from one-third to one-half that necessary for solid brick. Smaller expense of transportation due to decreased weight of product. Full protection against dampness and temperature. Possibility of terra cotta decoration on exterior of block.

In some states shales are used for making hollow-ware, while in others plastic clays are employed. Calcareous clays are undesirable as being unsuited to the production of a vitrified ware.

The composition of clays used for hollow ware varies so, that no one can be selected as typical, but it may be said that several of those analyzed from the Virginia Coastal Plain agree closely with hollow-ware clays used in other states.

POTTERY MANUFACTURE.

It seems doubtful whether the clays of the Coastal Plain region, thus far examined, can be used for any form of pottery other than common red earthenware. A few could be employed for a low grade of stoneware, but the product could probably not compete successfully with the cheap stoneware made in Ohio or Pennsylvania, and shipped in enormous quantities to neighboring states.

Raw materials.—The clays used for making common red earthenware, such as flower pots, are usually those beds of the poorer grades of clay, which are of good plasticity, free from grit, and burn to a porous, but often steel-hard body at from cone 05 to 03. Some are even burned at 010. Clays of this type are not uncommon in the Pleistocene formations of the Coastal Plain. If they are too dense-burning, even at these low cones, fine sand can be added to preserve the porosity.

Stoneware, at the present day, is usually made of a No. 2 fire clay, which can be burned to a hard, nearly vitrified body, and is also sufficiently refractory to take a slip glaze (an easily fusible clay), or an artificial glazing mixture, which may melt at cone 4 or so.

On this account, low grade clays are undesirable. Those near Curle's Neck, Virginia, for example, are not sufficiently refractory

*Iowa Geological Survey, Vol. XIV., p. 213.

to stand up at the heat required to melt the glazes now commonly used for stoneware. They would require a glaze of very low fusibility or have to be glazed with salt, which can be done at about cone 1.

Manufacture.—The clay for pottery manufacture has to be thoroughly mixed in order to render it perfectly homogeneous, and free from air bubbles. To this end it is first tempered in some form of pugmill, and then wedged. This latter operation consists in taking a large lump of the tempered clay, cutting it in two, bringing the two parts together with force, and then kneading the reunited lumps, this treatment being repeated a number of times. The molding is accomplished by several methods. Turning is done on a rapidly turning horizontal wheel, the potter taking a lump of clay and placing it on a revolving disk. Wetting the surface with a slip of clay and water, he gradually works the whirling mass up into the desired form. After being turned, the object is then detached from the wheel by running a thin wire underneath it, and is set on shelves in the drying room. Only articles with a circular cross-section and thick walls can be formed in this manner, since they have to hold their shape under their own weight.

Jollying or jigging is a more rapid method than turning, and the clay for this purpose is tempered to a softer consistency. The jolly is a wheel fitted with a hollow head to receive the plastic mold, the interior of which is the same shape as the outside of the object to be molded. A lump of clay is placed in the revolving mold and shaped into the proper form, first by means of the fingers, and lastly with the aid of a template attached to a pull-down arm, which is brought down into the mold. Cups, jars, jugs, and the larger flower pots are molded in this manner. A modification of this method, termed *pressing*, is used for the smaller size of flower pots. A pressing machine consists of a revolving steel mold, with a steel plunger of the shape and size of the interior of the pot. The tempered clay is first put through a plunger machine from which it issues in the form of columns, which are cut up by wires into a number of pieces, each containing just enough clay for making a pot of the desired size. These lumps of clay are then placed, one at a time in the mold, and the latter raised by means

ND CHEMICAL

Laboratory No.	Color	LOCALITY	CONE 010 Color	% Absorption	Fire Shrinkage	CONE 05 Color	
1300	Yel. buff	Brick mixture, Maynard ers, Richmond..........	Lt. red	17.40	1.6	Lt. red	00
1302	Yel. buff	Fort Lee....................	Lt. red	20.2	1.6	Lt. red	02
1305	Gray blk.	Two miles south of Cheste	Lt. red	18.2	1.3	Lt. red	05
1306	Yel. buff	One mile northwest of B Hundred..........	Lt. red	22.04	5.7	Lt. red	06
1307	Yel. buff	Keeler's yard, Broadway pomattox River..........	Lt. red	17.9	5.0	Lt. red	07
1311	Yel. buff	Sturgeon Point.	Lt. red	16.8	2.3	Lt. red	11
1312	Gray	Oldfield	Pink buff	16.3	1.6	Pink buff	12
1313	Buff	Oldfield	Lt. red	17.5	1.6	Lt. red	13
1314	Yel. buff	Ball Property six miles s east of Richmond.....	Lt. red	17.7	4.7	Lt. red	14
1315	Yel. buff		Lt. red	19.5	3.	Lt. red	15
1316	Lt. gray		Pk. cream	16.03	4.3	Pk. buff	16
1322	Br. buff	Impure diatomaceous Richmond..........	Lt. red	14.62	.6	Lt. red	22
1323	Buff		Lt. red	14.9	2.3	Lt. red	23
1324	Yel. buff	W. J. Ready's yard, chester, by Richmond	Lt. red	15.5	1.3	M. red	24
1325	Brown		Lt. red	17.5	2.	Lt. red	25
1326	Br. buff		Lt. red	16.4	.6	M. red	26
1330	Gray	Williamsburg road near Mill, Richmond..........	Pink	14.4	3.	Pink	1330
1331	Br. buff	Turner's yard near Peters	Lt. red	17.09	2.	Lt. red	1331
1333	Lt. br'n	Wood's yard near Emporia	Lt. red	16.30	1.	Lt. red	1333
1334	Lt. br'n	Clays showing variable acter of upper bed at geon Point..............	Lt. red	17.7	1.6	Lt. red	1334
1335	Gray		Pink	15.7	.3	Pink	1335
1336	Gray		Pink	15.08	s. s	Lt. red	1336
1336A	Gray	Clay from river level, St Point	Bluish red	20.54	2.	Lt. red	1336A
1339	Br. buff	City Point	Lt. red	17.2	3.3	Lt. red	1339
1343	Gray	Standard Brick Co., south folk........................	Pinkish	14.6	1.6	Pinkish	1343
1344	Drab	Blue clay, Suffolk Clay Co folk..........................	Pink	16.9	4.	Pink	1344
1345	Buff	Brick mixture, Suffolk Cl Suffolk......................	Pink	15.4	3.	Lt. red	1345
1350	Pink	Eocene clays from bets Stafford C. H. and Fre icksburg..................	Lt. red	28.2	2.6	Pink	1350
1352	White		Pk. white	25.4	.0	....	1352
1353	Yel. br'n	Between Milford and Bo Green........................	Lt. red	16.6	2.	Lt. red	1353
1354	Gr'n gray	One mile south of Layton...	Lt. red	26.80	.0	Lt. red	1354
1356	Light red	Red clay, northwest of F icksburg....................	Lt. red	28.01	4.	Lt. red	1356
1358	Light red	Diatomaceous earth, one south of Layton...........	Lt. red	21.73	.6	Lt. red	1358
1362	Lt. br'n	Pleistocene clay, Wilmont..	Lt. red	12.84	.0	....	1362
1363	White	Diatom. earth, Wilmont....	Yellowish	50.96	1.6	Lt. pink	1363
1365	Buff	Clay from "House" bank east of Wilmont............	Pk. cream	15.2	.0	Pk. cream	1365
1367	White	Sandy clay, Occupacia P. O.	Lt. red	29.89	.6	Lt. red	1367

*FeO, 1 per cent.

s. s. Slightly swelled.

The chemical analyses for this report w Virginia Polytechnic Institute

ver, until the plungers fit into it, thus pressing the clay into old. The bottom of the mold is movable, so that as the is lowered the bottom rises and pushes out the pot. Such nes have a large capacity, and are now used at most flower pot ies for pots up to seven inches diameter.

earthenware is commonly burned in circular or rectangular ft kilns.

CHAPTER V.*

TAILED ACCOUNT OF THE VIRGINIA COASTAL PLAIN LOCALITIES.

e following discussion does not attempt to include every clay sit in the Virginia Coastal Plain or Tidewater belt. In the at my disposal the endeavor was made to visit all the de- ts which were being actively worked and which appeared to promising, and it is felt that the results are sufficiently detailed afford one a fairly accurate idea of the clay resources of this ion. In this chapter the subject is discussed from the eco- mic standpoint. The descriptions of the different localities are ken up from north to south and in general from west to east, the main exception being the descriptions of the diatomaceous earth deposits which are grouped by themselves.

The Virginia Coastal Plain region lies east of a line passing through Alexandria, Fredericksburg, Bothwell, Richmond, Petersburg and Emporia, and having an area of approximately 9,500 square miles.

The region is traversed by many southeast flowing rivers, which cut the area into a number of broad low ridges.

The Coastal Plain formations consist in general of a series of clays, sand, and gravels, with some beds of greensand. These beds, which range in age from early Cretaceous to Pleistocene,

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dip very gently to the east and southeast at the rate of about 10 to 12 feet per mile (according to B. L. Miller), so that if the outcrop of a formation is at the western edge of the Coastal Plain, it would be at a much greater depth near the sea coast. Or, again, if a formation were found at sea level at a point midway between the coast line and the fall line, its dip would carry it higher up if it were followed inland, or lower down if followed toward the coast.

Of the different materials going to make up the deposits, the sands seem to be the most prominent, the clays being found at scattered localities, either on the surface or interbedded with the sands, and rarely forming deposits of great extent. In fact they seem in most cases to be of lenticular or lens-shaped character. The majority are red-burning, while only a few are buff-burning. No white-burning clays have been found; but even though they lack in variety so far as their color-burning qualities are concerned, it is probable that their possible uses are more numerous than is now supposed, and it is hoped that the tests given in this report may serve to encourage their development.

ALEXANDRIA COUNTY.

THE ALEXANDRIA AREA AND VICINITY.

This area is the most important brick-making district in the Virginia Coastal Plain region. It cannot be said that this marked local expansion of the clay-working industry is due to the more abundant occurrence of clay at this point, but rather to the fact of its nearness to an active and important market, namely, the city of Washington. Nearly all the brick yards of the area here described are situated so close to the city, that the product is hauled across the river by teams, and the daily continuous procession of wagons loaded with brick indicates the demand for the Virginia product.

The clays used in the Alexandria district are the Columbian loams, which underlie the low hills around Alexandria, Arlington, Addison, Riverside, etc.* They are all sandy loams of variable color, yellow, red, brown and bluish gray, and are frequently of

*Their distribution is shown on the Washington Folio, of the U. S. Geological Survey.

mottled character. Most of the clays burn to a red brick, but certain ones show a tendency to fire buff, and since these lighter burning parts are oftentimes tougher, they do not mix readily with the red-burning clay when the run of the bank is used, so that the buff spots show in the brick after burning. At the yard of the Washington Hydraulic Pressed Brick Company, the several clays are carefully separated and burned alone, thus giving several different shades of product.

Owing to the extent of the deposits and the amount of clay used, many of the yards dig their clay with a steam shovel, this being a rapid and economical method, but one to be employed only when the clay can be mixed from the top to the bottom of the bank. At the hydraulic works, where the different beds are separated, a wheel scraper or special form of clay gatherer is employed.

At most of the yards the clay is put through a pair of rolls, and pugmill before it passes to the press. Several types of the latter are used in this area. At one or two yards molding is done by hand; an equally small number use a stiff-mud machine, and one a dry press. The majority, however, use a peculiar type of machine known as the Trenton Wheel Machine. This consists of two large wheels, revolving slowly in opposite directions. A series of mold boxes, is set into the rim of one of these, each mold box having an easily movable bottom, to which is attached a thick stem, which passes through a plate set below the mold. As the wheel revolves, the movable bottom falls to the bottom of the mold as it comes on top of the wheel, and rises in the mold relatively, but actually drops, as any one mold reaches its lowest point in the revolution of the wheel. Two screen boards fit up closely against the rim of the wheels where these converge above, the boards and edges of the wheels thus forming a sort of hopper. As the wheels revolve the clay is charged into the hopper, and falling in between the rims of the wheels as they go around, is forced into the molds. As the filled mold reaches its lowest or inverted position, the movable bottom drops and the green brick is pushed out onto a belt. The brick is rather rough and granular even for a common one, and it is usually repressed. It is remarkable to find this machine so extensively used at this one locality for common brick making, as it takes up much space, requires much power, is cumbersome, of

limited capacity, and does not give any smoother product than a soft-mud machine. At those yards where stiff-mud machines are employed, they seem to give good results.

Drying is done on open yards, on pallets, or in a number of cases in tunnel driers. Throughout the Alexandria region, the kilns employed are with few exceptions up-draft with permanent side walls. A few use scove kilns, and the Hydraulic Company has down-draft ones.

The firms in operation in this region are: Washington Hydraulic Pressed Brick Company; Jackson-Phillips Company; Potomac Brick Company; Virginia Brick Company; Estate of Charles Ford; Walker Brick Company; West Bros.; Alexandria Brick Company; Washington Brick and Terra Cotta Company; and American Hygienic Brick and Tile Company. The last is located near Riverside.

SPOTTSYLVANIA COUNTY.

THE FREDERICKSBURG AREA.

There is only one small yard at this locality, namely, that of the Fredericksburg Brick Works, which is located on the western edge of the town. The material used is a red silty clay, containing small angular quartz grains, and is possibly a residual clay, which has been worked to some extent by water. The material burns to an excellent red color, but not to a very dense body. It is utilized for common brick, and molded in an end-cut auger machine, it being claimed that fewer cracked bricks are obtained than when a soft-mud machine was used. The bricks are dried on pallets and burned in Dutch kilns.

The most prominent clays in the region around Fredericksburg are those belonging to the Eocene formation. While these no doubt underlie a considerable area between Fredericksburg and Stafford to the north, still prominent outcrops of them are not very abundant.

The nearest of these to Fredericksburg is located along the road from Fredericksburg to Davis' granite quarry on the hill leading up from the canal. This material, which is of a bright red color, is known, locally, as paint clay,and is said to have been used by the Indians for that purpose. How extensive the bed is can only be determined by boring, for no outcrops of it are seen, except along the

View of Washington Hydraulic-Press Brick Company's Works.

road, but there it is exposed in the ditch at the roadside for several hundred feet at least. The clay (Lab. No. 1356) which slakes down fast, works up to a very plastic mass with 33 per cent. of water, and has but little grit. The air shrinkage is 9.6 per cent., and the average tensile strength is 79.9 pounds per square inch. In burning it behaved as follows:

WET-MOLDED BRICKLETS.

Cone	*010*	*05*	*03*	*1*	*3*	*5*	*8*
Fire shrinkage	.6	4	6	11	12.3	12.6	13.3
Color	lt. red	lt. red	red	dk. red	dk. red	dk. red	dk. red
Absorption	28.01	21.70	15.40	4.08	1.4	.18	.02

DRY-PRESSED BRICKLETS.

Cone	*1*	*3*
Fire shrinkage	8	9
Color	dk. red	red
Absorption		11.45

Its chemical composition was:

Silica (SiO_2)	55.33
Alumina (Al_2O_3)	25.69
Ferric oxide (Fe_2O_3)	9.02
Lime (CaO)	.22
Magnesia (MgO)	.08
Soda (Na_2O)	.25
Potash (K_2O)	2.57
Titanic oxide (TiO_2)	.81
Ignition	6.00
	99.97
Total fluxes	12.14

This is a red-burning clay which reaches steel hardness at cone 1, burning to a rich red color at that heat, but showing a sudden and marked increase in its fire shrinkage. The total shrinkage of this clay is too high to permit its being used alone for the manufacture of clay products. At cone 8 it is practically vitrified. The main use of this clay would seem to be for the manufacture of mineral paint.

Following the road from Fredericksburg to Stafford, there are a number of indications of bluish-white Eocene clay in the ditches along the road side but most of these are topped by a heavy bed of sand. About six miles east of north from Fredericksburg, a heavy bed of the clay is found on top of a ridge.

The section here involves:

Surface sand and soil	1—2 feet
Pink clay, laminated	12 feet
Whitish clay	4 feet

The pink clay (Lab. No. 1350) is distinctly stratified and in its upper part contains some scattered crusts of limonite. It slakes fairly fast, and works up with 36.3 per cent. water to a mass of moderate plasticity and little grit, whose air shrinkage is 9.3 per cent. and whose average tensile strength is 115.3 pounds per square inch. In burning it behaved as follows:

WET-MOLDED BRICKLETS.

Cone	010	05	03	1	3	5	8
Fire shrinkage	.6	2.6	3.6	7	9	10.3	10.3
Color	light red	pink	light red	light red	light red	red brown	red brown
Absorption	28 2	23.1	14.20	12.06	7.91	3.50	3.74

DRY-PRESS BRICKLETS.

Cone	1
Fire shrinkage	7
Color	light red

Its chemical composition was:

Silica (SiO_2)	51.12
Alumina (Al_2O_3)	26.14
Ferric oxide (Fe_2O_3)	10.70
Lime (CaO)	.10
Magnesia (MgO)	.25
Potash (K_2O)	1.78
Soda (Na_2O)	.77
Titanic oxide (TiO_2)	.47
Ignition	8.63
	99.96
Total fluxes	12.87

The clay, although burning to a good color, is not a dense-burning one, in fact it does not yield as tight a body as some of the Pleistocene clays. It burns steel-hard at cone 1, but does not make a product of low absorption until cone 8 is reached. Its main use would be for common brick, pressed brick or drain tile. It seems too low in plasticity to work on a stiff-mud machine. The outcrop mentioned is somewhat distant from the railroad for cheap exploitation, but the extension of this bed should be found to the westward, nearer lines of transportation.

The whitish clay (Lab. No. 1352) which underlies the pink clay, slakes moderately fast and works up with 35.2 per cent. of water to a mass of good plasticity whose air shrinkage is 8.6 per cent. and the average tensile strength 113.7 pounds per square inch.

In burning it behaved as follows:

WET-MOLDED BRICKLETS.

Cone	*010*	*05*	*03*	*1*	*3*	*5*	*8*
Fire shrinkage	.6	1.6	2.6	5	6.3	7.6	10
Color	pink	white	cream	cream	buff	buff	drab
Absorption	25.4	22.2	19.6	13.2	13.1	8.30	2.49

DRY-PRESS BRICKLETS.

Cone	*1*
Fire shrinkage	4
Color	cream

The chemical analysis yielded:

Silica (SiO_2)	57.26
Alumina (Al_2O_3)	28.97
Ferric oxide (Fe_2O_3)	3.10
Lime (CaO)	.04
Magnesia (MgO)	.19
Potash (K_2O)	1.40
Soda (Na_2O)	.42
Titanic oxide (TiO_2)	.14
Loss on ignition	8.44
	99.96
Total fluxes	5.15

This is a buff-burning clay, which burns to a good body, becoming steel-hard at cone 05. It does not vitrify, however, until cone 8, at which temperature its total shrinkage is quite high. It would no doubt make a good light-colored pressed brick by either the wet method repressed, or the dry-press process, and up to cone 5 has an excellent color. It is not a fire clay.

KING GEORGE COUNTY.

THE WILMONT AREA.

This is practically the only locality along the Rappahannock river where the Pleistocene clays are worked, and the quality of those developed at this point would make it seem desirable to prospect further for other deposits.

At the brick works at Wilmont the following section is exposed:

Soil	1 ft.
Blue clay (so-called)	5— 6 ft.
Gravelly sand (variable thickness)	6—15 ft.
Diatomaceous earth	10 ft.
Green sand clay	4 ft.

The blue clay, which is of Pleistocene age, is mixed with either the diatomaceous clay, or with clay from another surface deposit not far distant. The green sandy clay, which is the same as that tested from Layton, lies below the level of the yard. Pl. XV, Fig. 1. shows the Pleistocene clay overlying the diatomaceous earth.

Another deposit of Pleistocene clay, known as the House Clay, is dug about one-fourth mile northeast of the brick works. Here the clay runs from 9 to 13 feet in thickness and is underlain by sand. Still another deposit has been located one-half mile northwest of the brick yard. Only the House Clay (Lab. No. 1365) and that at the brick yard (Lab. No. 1362) were tested. Their properties were as follows:

	1362	1365
Water required	19.2	22
Slaking	mod. fast	mod. fast
Plasticity	good	good
Grit	some	much
Air shrinkage	7.3	7.6
Average tensile strength	130.8	87.1

WET-MOLDED BRICKLETS.

Cone 010		
Fire shrinkage	0	s. s.*
Color	light red	pink cream
Absorption	12.84	15.2
Cone 05		
Fire shrinkage	0	0
Color	light red	pink cream
Absorption	12.00	14.4
Cone 03		
Fire shrinkage	1	.3
Color	light red	pink cream
Absorption	10.3	14.01
Cone 1		
Fire shrinkage	2.6	1.3
Color	light red	yel. brown
Absorption	8.5	12.22
Cone 3		
Fire shrinkage	2.3	1.6
Color	light brown	brown
Absorption	6.1	10.72
Cone 5		
Fire shrinkage	3	1.3
Color	red	buff
Absorption	5.9	11.2
Cone 8		
Fire shrinkage	4.3	2.3
Color	br. buff	buff
Absorption	2.03	9.87

*Slightly swelled.

DRY-PRESS BRICKLETS.

	1362	1365
Cone 1		
Fire shrinkage	1	0
Color	brown	buff
Cone 5		
Fire shrinkage	1	
Color	red	
Absorption	15.57	

CHEMICAL COMPOSITION.

Silica (SiO_2)	71.60	77.28
Alumina (Al_2O_3)	13.18	13.01
Ferric oxide (Fe_2O_3)	4.65	2.42
Lime (CaO)	.42	——
Magnesia (MgO)	.66	.70
Potash (K_2O)	1.58	1.22
Soda (Na_2O)	1.23	.68
Titanic oxide (TiO_2)	1.88	.06
Ignition	4.74	4.59
	99.94	99.96
Total fluxes	8.54	5.02

Although these clays are both surface clays, and occur in the same formation, at no great distance from each other, still they are quite dissimilar in many respects.

No. 1362 is a red-burning clay which burns to a good bright color. Its air shrinkage is not excessive and its fire shrinkage is low. It contains some coarse grit which shows up clearly on the fractured surface of the burned bricklet. At cone 8 portions of the clay become viscous. This is not a fire clay, but it works well for brick and fireproofing.

No. 1365 is a gritty, light-burning clay which does not burn steel-hard until cone 5, and even at 8 still shows a rather high absorption. Its low air shrinkage and low tensile strength are characteristic of sandy clays. The material can be classed as a low-grade fire clay, such as is used in terra-cotta manufacture, or for boiler-setting brick. It is the most refractory of the series tested from the Coastal Plain area.

The brick works at Wilmont (Pl. XV, Fig. 2.) produce fireproofing, boiler brick and some front brick. In each case a mixture of the Pleistocene clays, or of these with the diatomaceous earth is used.

The clays are molded on either a stiff-mud or soft-mud machine, and dried in tunnels. Burning is done in up-draft kilns. The product is all shipped by water, as the yard is located on the bank of the Rappahannock river.

ESSEX COUNTY.

THE LAYTON AREA.

Along the shore of the Rappahannock river about 1 mile south of Layton, there is a long outcrop of gritty greenish clay, of Miocene age, which is evidently part of a rather extensive deposit. The material is well shown in the river bluff, and its smooth vertical surface stands out in marked contrast to the overlying sand. The bed as here exposed is not less than 9 feet thick, and is overlain by 6 to 8 feet of sand which may be adapted to molding purposes. The clay (Lab. No. 1354) evidently underlies the diatomaceous earth which crops out farther down the river, and both are overlain by the sand referred to above. This same clay is seen inland from the river, behind the mill at Occupacia postoffice; it also underlies the diatomaceous earth at Wilmont, and is seen at several other points along the river bank. It was hoped that since there was a great abundance of the material, that it might prove of economic value, and, accordingly, it was tested in the usual detailed way; but the results given below are rather disappointing.

Water required, 24.2 per cent.; slaking, slow; plasticity, low; grit, much, especially in certain layers; air shrinkage, 6 per cent.; average tensile strength, 41.2 pounds per square inch. In burning it behaved as follows:

WET-MOLDED BRICKLETS.

Cone	*010*	*05*	*03*	*1*	*3*	*5*	*8*
Fire shrinkage	s. s.*	0	.3	1	1.6	2	2.3
Color	light red	light red	light red	light red	red	brown	red brown
Absorption	26.80	27.50	27.77	27	25.5	27.9	24.79

*Slightly swelled.

CHEMICAL COMPOSITION.

Silica (SiO_2)	85.72
Alumina (Al_2O_3)	5.83
Ferric oxide (Fe_2O_3)	1.74
Lime (CaO)	1.01
Magnesia (MgO)	.11
Potash (K_2O)	1.31
Soda (Na_2O)	.64
Titanic oxide (TiO_2)	.06
Ignition	3.55
	99.97
Total fluxes	4.81

It is exceedingly sandy as can be told by the feel, and seen from the analysis (silica, 85.72 per cent.). Its shrinkage is very low and it burns to a very porous body, so that it would seem undesirable to use it for even common brick.

Overlying this at Occupacia postoffice is a whitish sandy clay, which, although quite different in appearance from the green clay, resembles it closely in both physical and chemical properties. One might suppose, judging from its color, that it was a fire clay, or at least semi-refractory in its character, but it is not.

The clay (Lab. No. 1367) slakes fast, and works up with 26.4 per cent. of water to a fairly plastic mass, which is very sandy, but it has an air shrinkage of 8.6 per cent. Its average tensile strength was 54.2 pounds per square inch. In burning it behaved as follows:

WET-MOLDED BRICKLETS.

Cone	010	05	03	1	3	5	8
Fire shrinkage	0	.6	1.6	2	2.3	2.6	5
Color	lt. red	lt. red	lt. red	pink	lt. red	brown	brown
Absorption	29.89	28.3	27.72	23.34	23.7	23.05	19.00

The chemical composition was:

Silica (SiO_2)	84.64
Alumina (Al_2O_3)	7.73
Ferric oxide (Fe_2O_3)	2.59
Lime (CaO)	.10
Magnesia (MgO)	.17
Potash (K_2O)	1.12
Soda (Na_2O)	.32
Titanic oxide (TiO_2)	.24
Ignition	3.06
	99.97
Total fluxes	4.30

This clay does not burn steel-hard until cone 8, and is not dense burning. It is doubtful if it can be put to any special use, as even for common brick it is too sandy.

THE DIATOMACEOUS EARTH DEPOSITS.

Diatomaceous earth, tripoli, or infusorial earth as it is variously called, is a fine, silty, or clay-like material, which, when pure, is made up almost entirely of the tests of diatoms. It may be of variable color, ranging from white, yellow, brown, etc., and it is very light in weight; porous and soft. In the Atlantic Coastal Plain, deposits of it are by no means uncommon in the Miocene formations, and those around Richmond have long been known, and are referred to in many publications.

There the beds outcrop in great thickness in the embankment along the tracks by the Richmond Locomotive Works, as well as along the sides of the valley to the west. The general character of the earth is that of a silty, porous clay, which breaks out in irregular lumps. In places it is traversed by vertical fissures, which

are filled with limonite. Along the Rappahannock river there are long exposures of the diatomaceous earth. In places it forms great bluffs of a yellowish white color, which stand out prominently in the sunlight and can be seen for a long distance (Pl. XIV, Fig. 2.). This earth appears to be purer and lighter than that around Richmond, but still in places it passes into a clay.

Samples were collected from several localities and examined with some care. Microscopically examined they proved to be somewhat disappointing for the reason that most of them contained very few diatoms, and in some, which to the feel appeared like diatomaceous earth, hardly any diatoms could be found. This is due to the fact that the diatoms are not uniformly distributed through the deposit, but are found chiefly in certain layers. The results of the physical and chemical tests are given below:

Lab. No.	1322	1323	1358	1363
Color, moist	brown buff	buff	light yellow	white
Water required	31.6	34.6	23.1	62.4
Slaking	fast	fast	fast	fast
Plasticity	lean	lean	low	low
Grit	some	some	little	some
Air shrinkage	13	14	10.3	3.6
Average tensile strength			29.4	34.4
Cone 010				
Fire shrinkage	.6	.6	.6	1.3
Color	light red	light red	light red	yellowish
Absorption	14.62	14.9	21.73	50.96
Cone 05				
Fire shrinkage	.6	2.3	.6	1.6
Color	light	light	light	light pink
Absorption	13.6	10.9	20.70	48.4
Cone 03				
Fire shrinkage	2	3.3	2.3	1
Color	light red	light red	light red	pink
Absorption	12 42	9.0	15.88	44.70
Cone 1				
Fire shrinkage	3	5	5.6	4.6
Color	light brown	medium red	pink	pk. cream
Absorption	9.1	4.16	11.3	41.4
Cone 3				
Fire shrinkage	3.3	6	5.6	4.6
Color	red brown	medium red	red gray	yellow
Absorption	6.9	2 30	9.5	40.9
Cone 5				
Fire shrinkage	5	6	6	5.3
Color	red gray	red gray	light brown	yellow
Absorption	5.06	1.70	5.4	38.3
Cone 8				
Fire shrinkage	2	5.5	6.3	5.6
Color	brown	red gray	light brown	yellow br.
Absorption	2.04	1.08	2.57	32.32

The following analyses of the earths collected from different points show their chemical composition:

Silica (SiO_2)	70.42	63.17	78.82	82.85
Alumina (Al_2O_3)	15.15	19.30	9.24	6.76
Ferric oxide (Fe_2O_3)	5.17	6.32	5.42	2.34
Lime (CaO)	.14	.06	.04	.35
Magnesia (MgO)	.79	.69	.12	1.06
Potash (K_2O)	2.24	2.45	1.51	1.07
Soda (Na_2O)	.39	.69	.81	.99
Titanic oxide (TiO_2)	.44	.88	.33	1.09
Ignition	5.21	6.39	3.66	3.40
	99.95	99.95	99.95	99.91
Total fluxes	8.73	10.21	7.90	5.81

The location of these samples is as follows:

No. 1322. Weathered diatomaceous earth from 7th St., near Richmond Locomotive Works, Richmond. This, after burning, closely resembles the diatomaceous earth from along the Rappahannock river near Layton. It seems to be vitrified at cone 5, and at cone 8 is viscous.

No. 1323. This sample was also collected from the same locality as No. 1322, but farther from the surface. It is quite impure, and shows a high air shrinkage. It burns red and becomes steel-hard at cone 05. It is vitrified at cone 5, and nearly viscous at cone 8.

No. 1358. Diatomaceous earth from along the Rappahannock river south of Layton. This burns fairly dense at the higher cones, and gives a clean color, but is quite porous at the lower cones.

No. 1363. Diatomaceous earth from Wilmont. This burns to a very porous body as can be seen from the absorption figures. It has a low air and fire shrinkage.

It will be seen from an inspection of the chemical analyses that these earths show much variation in their chemical composition. All are quite siliceous, and one of them highly so. Nos. 1322 and 1323 represent the fresh and weathered parts respectively of the same bed. The weathered material is more siliceous and contains a lower quantity of fine particles and soluble substances, due probably to the leaching action of water filtering through it from the surface. The higher silica content seems also to affect its porosity and shrinkage in burning. It will also be noticed that the most siliceous one, namely, No. 1363 from Wilmont, is exceedingly porous after being burned.

Uses of diatomaceous earth.—Though occurring in Virginia in great abundance, the deposits of diatomaceous earth are but little worked. There are several uses to which the material has been put, the most important of which is as an abrasive. For fine polishing or rubbing it should be of value, since the small, siliceous diatom cases

possess more or less cutting power, but as the abrasive action depends on these, it is quite evident that the presence of clay impurities will decrease the abrasive power of the material. This probably accounts for the failure of much of the Virginia earth to be employed for such purposes. In this connection it should be stated that some of the Virginia material contains a large number of diatoms, and it is such beds that should be chosen. A microscopical examination will at once show whether or not the material contains many diatoms.

A second use of diatomaceous earth is for the manufacture of boiler coverings. For this purpose it is commonly mixed with asbestos, and gives a mixture which forms an excellent non-conductor of heat.

Diatomaceous earth has also been employed as an absorbent for nitroglycerine in the manufacture of dynamite, but little is now used for that purpose.

CAROLINE COUNTY.

THE MILFORD AREA.

Along the road from Milford to Bowling Green, and about three-quarters of a mile from the former locality, there is a promising deposit of yellowish brown Pleistocene clay, 10 to 12 feet thick. The bed is underlain by sand, but has very little overburden. It (Lab. No. 1353) works up with 27.5 per cent. of water, and has good plasticity, but its air shrinkage is high, namely, 11 per cent. The average tensile strength is 193.6 pounds per square inch. Its behavior in burning was as follows:

WET-MOLDED BRICKLETS

Cone	*010*	*05*	*03*	*1*	*3*	*5*	*8*
Fire shrinkage	.3	2	2	4	4.3	5	5
Color	lt. red	lt. red	red br.	red	red	red br.	red br.
Absorption	16.6	13.3	11.79	9.70	5.32	2.09	2.02

DRY-PRESS BRICKLETS

Cone	*1*	*3*
Fire shrinkage	3	3
Color	dk. red	gray
Absorption		41.34

The chemical analysis yielded:

Silica (SiO_2)	69.00
Alumina (Al_2O_3)	15.58
Ferric oxide (Fe_2O_3)	6.72
Lime (CaO)	.06
Magnesia (MgO)	.15
Potash (K_2O)	2.34
Soda (Na_2O)	.91
Titanic oxide (TiO_2)	.10
Ignition	5.09
	99.95
Total fluxes	10.18

This is a red-burning surface clay, which becomes steel-hard at 03, but is too gritty to use for any purpose except common-brick manufacture. It would possibly work on a dry press machine.

HENRICO COUNTY.

THE RICHMOND AREA.

Richmond, next to Alexandria, is the most important clay working center in the Coastal Plain region of Virginia, there being a number of yards engaged in the manufacture of common and in some cases pressed brick. Most of these are located on the edge of Richmond and in the suburbs of Manchester and Fulton, while a few are located near the reservoir and race track.

The output of these is not sufficient to supply the demand, and some outlying towns are also drawn upon. The better grades of pressed brick in Richmond are not made in the Coastal Plain area. Some are obtained from Clayville, Va., but most of them come from points outside of the State.

There are four yards in operation in Manchester, all of them being located in the vicinity of Knight and Maury streets. All of these are engaged in the manufacture of soft-mud brick and a few of them also produce a small quantity of pressed brick. The clay used is a more or less mottled, gritty, yellow or reddish clay, which is covered by a thin layer of sandy soil and commonly underlain by a bed of sand. At only one point, namely, the yard of Green and Harrison, is an underlying crystalline rock encountered. The clays in general are very tough and plastic, sometimes quite sandy, and they contain a variable quantity of stony material which ranges in size from small pebbles up to large boulders, most of these being of crystalline character. This stony material is not found to be uniformly distributed through all the

beds, but seems to run rather in streaks, the greatest quantity of it having been observed in the bank of W. J. Ready, and Green and Harrison (Pl. X, Fig. 2.).

At G. E. Redford's yard (Pl. X, Fig. 1.) the clay shows an average thickness of 12 feet with a maximum of 17 feet, and is underlain by a hard bed of sand and gravel. It is a mottled gritty clay with scattered mica fragments and many limonite stains running through it; and it contains also many decomposed pebbles of crystalline rock. The clay pit is a large shallow excavation lying to the south of the yard and the working face has a height of from 6 to 8 feet. The material is red-burning and for the manufacture of bricks the run of the bank is commonly used. This is necessary because the clay seems to vary somewhat in its physical character. Thus, for instance, it is not safe to use that found in the north end of the pit alone, because it is very tough and cannot be used without cracking. It is mixed in, therefore, with the more sandy portions of the bed. The brick are molded by hand and dried in open yards and burned in up-draft kilns with permanent side walls. The fuel used is wood or coal. When there is a call for front brick some of the hand-molded ones are repressed in a hand-power machine.

Adjoining the yard of Redford on the west is that of W. B. Davis. This pit, which is a large shallow excavation, lies to the south of the yard, and has a working face of from 6 to 7 feet in height. The clay is similar to that in Redford's bank, but seems to contain fewer stones. It is claimed that it runs 20 to 25 feet in depth, and is underlain by whitish sand. The bricks are molded by hand, dried on open yards, and burned in up-draft kilns, with permanent side walls. The fuel used is wood and coal.

Adjoining Davis' yard on the east is that of W. J. Ready. The clay pit which lies to the northwest of the yard is much deeper than the neighboring excavations and also lies at a slightly lower level, for the upper surface of the clay is uneven and slopes towards the river. The clay in general is somewhat similar to that found at the two preceding yards but contains more stones and boulders than are found in either Redford's or Davis' bank. The thickness of the clay is said to be at least 18 feet, and it is probably underlain by sand. Here in a working face of perhaps 200 feet in length they recognize three different kinds of clay, only one

A. General view of Redford's clay bank and brick yard, Manchester.

B. View of a clay pit at Manchester by Richmond, showing the boulders found at times in the clay of this vicinity,

of which they claim can be used alone. If either of the other two is used by itself, it results in an imperfect product. The physical and chemical characters of these three clays are as follows:

Locality No.	1324	1325	1326
Color	yellow buff	brown	brown buff
Water required	20.3	20.3	18.7
Slaking	mod. fast	mod. fast	fast
Plasticity	good	good	fair
Grit	sandy	much	sandy
Air shrinkage	7 per cent.	6 per cent.	6 per cent.
Average tensile strength	93.7	132	99
Cone 010			
Fire shrinkage	s. s.*	s. s.*	s. s.*
Color	light red	light red	light red
Absorption	15.5	17.5	16.4
Cone 05			
Fire shrinkage	1.3	2	.6
Color	red	light red	red
Absorption	12.9	16.8	15.1
Cone 03			
Fire shrinkage	1.6	2.6	1
Color	red	med. red	red
Absorption	11.4	12.07	14.4
Cone 1			
Fire shrinkage	3.7	3.6	2
Color	dark red	dark red	red
Absorption	6.2	9.8	10.3
Cone 3			
Fire shrinkage	5.3	4	3
Color	dark red	dark red	dark red
Absorption	3.4	8.7	8.2
Cone 5			
Fire shrinkage	5	5	5.6
Color	dark red	dark red	red
Absorption	1.4	6.29	1.6
Cone 8			
Fire shrinkage	5.5	vis. beg.	6
Color	dk. red brown	red brown	red brown
Absorption	.19	1.47	1

A chemical analysis of each of these yielded the following results:

	1324	1325	1326
Silica (SiO_2)	73.38	69.43	72.61
Alumina (Al_2O_3)	13.53	14.79	13.08
Iron oxide (Fe_2O_3)	5.53	6.70	5.61
Lime (CaO)	.58	.57	.96
Magnesia (MgO)	.14	.63	.23
Potash (K_2O)	2.32	2.26	2.45
Soda (Na_2O)	.47	.71	.44
Titanic oxide (TiO_2)	——	——	.44
Ignition	4.03	4.85	3.65
	99.98	99.94	99.96
Total fluxes	9.04	10.87	10.18

*Slightly swelled.

No. 1324, which was taken from the northwest corner of the bank, can be used alone. This burns to a good red color up to cone 03, but above that it deepens so that it becomes unsightly. At cone 5 it is very close to viscosity.

No. 1325, taken from the west side of the bank, is too tough to be used alone, and is mixed with 1326. When wet it is very plastic, even though quite gritty. At the same time it does not burn to a very dense body, and it has a comparatively low fire shrinkage. It becomes steel-hard at cone 1, and at cone 8 has reached the point of viscosity.

No. 1326, from the southeast corner of the bank, is very sandy, with a low fire shrinkage, and does not work well alone.

W. J. Ready also operates a plant near the West End yard, which is located a quarter of a mile west of the track near the reservoir. The material is the usual mottled surface clay which is worked to a depth of about 7 feet, although a total thickness of 20 feet is claimed for it. No information could be obtained regarding the character of the underlying material. Overlying the clay are about 4 feet of loamy material which is probably the weathered clay. For brick manufacture the run of the bank is used, the clay being tempered in a ring pit, molded on a soft-mud machine, and burned in Dutch kilns. The product consists entirely of common brick and no repressing is done at this yard.

Green and Harrison have a yard located just east of W. J. Ready's. The pit is a small one and contains a large quantity of boulders (Pl. X, Fig. 2.), while in the northwest corner of it the underlying gneiss has been struck. The clay is worked up by the same methods as those used at the adjoining yards.

The yard of the Fulton Brick Company, which is commonly spoken of as Westford's yard, is located west of the Chesapeake and Ohio Railway round house. The clay used here is the ordinary surface clay and does not seem to run over 10 feet in thickness. It also contains many cobble stones. Underlying this is a fine sand which is at least 8 feet deep and is used for sanding the brick molds. The clays here are tempered in ring pits molded by hand and burned in Dutch kilns. The product is almost exclusively common brick.

The Baltimore Brick Company operates two yards at Rockett, a suburb of Richmond. The yards are located near the intersection of Ohio and Williamsburg Avenues. The clay is tempered in ring pits, molded by hand, and burned in Dutch kilns. Some 12 years ago the company tried making soft-mud machine brick but gave it up for some unknown reason. The clay is obtained from under the surface at several points in the vicinity of the yard and averages from 15 to 18 feet in thickness with an underbedding of sand. The material is quite similar in its character to that at Manchester, but lacks the stones and boulders. At the more southerly of the two yards operated by the Baltimore Brick Company the clay is also molded by hand and burned in Dutch kilns. The product has a good ring but is not very smooth or bright in color.

Maynard & Powers operate a pit lying to the southeast of the Baltimore Brick Company's excavation. The working face here is about 12 feet high and shows a sandy, mottled, yellowish brown and gritty clay similar to that occurring in the other pits in this vicinity. The company claims that their clay runs 20 feet in depth and is underlain by a bluish gray sand. The properties of a sample (Lab. No. 1300), representing the run of the bank and used for brick manufacture, are as follows: Color, when moist, yellow buff; water required, 20.9 per cent.; slaking, moderately fast; plasticity, good; grit, fine; air shrinkage, 6.4; average tensile strength, 89.6. When burned the clay behaved as follows:

Cone	010	05	03	1	3	5	8
Fire shrinkage	0	1.6	1.6	5	6.3	6.6	6.3
Color	lt. red	lt. red	lt. red	red	dk. red	gray br.	red br.
Absorption	17.40	15.08	14.06	7.1	4.04	1.4	1.29

A dry-press bricklet burned to cone 1 had a fire shrinkage of 4 per cent. and burned to a light red color. This clay is to be classed as a common-brick clay which burns steel-hard at 05 and has an excellent red color at that cone. It gives a rather rich red at cone 1 but at cone 3 the color is too deep and impure to make a nice looking brick.

At cone 5 it appears to be vitrified, but contains too much fine grit to make a good paving-brick body. It is probable that in using this clay for brick manufacture it is not burned at a higher temperature than cone 010.

The chemical analysis of this clay yielded:

Silica (SiO_2)	71.50
Alumina (Al_2O_3)	13.86
Ferric oxide (Fe_2O_3)	4.78
Lime (CaO)	.56
Magnesia (MgO)	.11
Potash (K_2O)	2.29
Soda (Na_2O)	.81
Titanic oxide (TiO_2)	1.44
Ignition	4.61
	99.96
Total fluxes	8.55

At the yard where it is used the clay is tempered in ring pits. molded by hand, dried on open yards and burned in Dutch kilns, of which the company has three. The product is sold chiefly in Richmond.

A clay very similar in appearance to that on the Ball property 6 miles south of the city and probably of the same age is also found outcropping on the Williamsburg road leading to Stagg's Mill, about one-half mile to the west of where the road crosses the railroad. The clay is exposed on a sloping hillside, and in such a position that a large quantity can be removed without having to take off much overburden. It is also well located for shipment. As far as could be ascertained the bed is not less than 20 feet thick. It (Lab. No. 1330) is a grayish clay, which slakes slowly and works up with 27.8 per cent. water to a mass of high plasticity. Its air shrinkage, 12.6 per cent., is somewhat high; so also is the average tensile strength, namely, 300.9 pounds per square inch. In burning, it behaved as follows:

WET-MOLDED BRICKLETS.

Cone	*010*	*05*	*03*	*1*	*3*	*5*	*8*
Fire shrinkage	1	3	5	7.6	7.6	2	.3
Color	pink	pink	lt. red	red	dk. red	gray	drab
Absorption	14.4	8.9	5.65	1.07	.08	2.4	1.56

The chemical composition is:

Silica (SiO_2)	63.06
Alumina (Al_2O_3)	20.90
Ferric oxide (Fe_2O_3)	6.26
Lime (CaO)	.16
Magnesia (MgO)	.45
Potash (K_2O)	3.13
Soda (Na_2O)	.68
Titanic oxide (TiO_2)	.04
Ignition	5.29
	99.97
Total fluxes	10.68

This is a very plastic clay which becomes steel-hard at cone 05. It gives a light red color up to cone 03, but at cone 1 gives an excellent dark red color. Its point of vitrification is apparently reached at about cone 3, and at cone 5 it was well passed vitrification and had swelled considerably. It is not as good a clay as that described from near Bermuda Hundred (Lab. No. 1317) or Curle's Neck (Lab. No. 1314).

THE FORT LEE AREA.

At Fort Lee on the Chesapeake and Ohio Railway about 2 miles south of Richmond there is a group of yards operated, respectively, by C. H. Oliver, J. M. Davis and the Fulton Brick Company. The general run of the clays is not unlike those used around Richmond, but none of the pits show stony material such as is found in some of the Richmond clay banks.

The most southern of this group of yards is that of C. H. Oliver, which is located one mile west of Fort Lee. The clay here is found immediately underlying the surface and the bank shows 12 feet of clay, although the total thickness of it is said to be 20 feet. Underlying it is a pit of gravel and sand of unknown depth. For making bricks the run of the bank is used. An examination of the clay in the bank shows that the material is mottled in its character, the mottlings consisting of yellow and bluish-white clay, the latter being tougher than the former and unless the material is thoroughly pugged before molding, the bluish white clay shows up in the product in the form of light colored lumps.

The general physical properties of this clay (Lab. No. 1202) are as follows: Color, when moist, yellow buff; water required, 24.2; slaking, moderately fast; plasticity, good; grit, much, fine; air shrinkage, 8.6; average tensile strength, 60.6 pounds per square inch.

In burning it behaved as follows:

WET-MOLDED BRICKLETS.

Cone	010	05	03	1	3	5	8
Fire shrinkage	0	1.6	4	6.3	7	8.3	7.3
Color	lt. red	lt. red	lt. red	lt. red	lt. red	dk. red	brown
Absorption	20.2	17.6	14.06	7.5	5.9	2.60	1.10

A dry-pressed bricklet burned at cone 1 showed a light red color and a fire shrinkage of 4 per cent.

A chemical analysis of this material is as follows:

Silica (SiO_2)	69.55
Alumina (Al_2O_3)	15.79
Iron oxide (Fe_2O_3)	6.05
Lime (CaO)	trace
Magnesia (MgO)	.08
Potash (K_2O)	1.54
Soda (Na_2O)	.38
Titanic oxide (TiO_2)	1.06
Ignition	5.52
	99.97
Total fluxes	8.05

This would be classed as a common-brick clay which burns to an excellent light-red color up to 03; a rich red at cone 1, and which vitrifies not far from cone 5. At cone 8 it is beginning to swell, due to the fact that portions of the matrix fuse. These fused parts are evidently small limonite specks which are scattered through the clay. The chemical analysis indicates its siliceous character, and also its red-burning qualities, while the percentage of total fluxes shows that it is not of high refractoriness. In the working of this clay care has to be taken to pug it thoroughly, otherwise the lumps of unpugged clay are apt to cause trouble in the drying and burning of the ware. The sand for the molds is obtained from the foundries, and, on account of its high iron percentage, helps the color of the brick. In the process of brick manufacture at this yard the clay is first put through rolls and passed from there through a soft-mud machine. The bricks are all dried on pallets and the burning is done in Dutch kilns. In the last mentioned stage of the process they get a settle of about 15 inches in 38 courses.

Adjoining Mr. Oliver's yard on the west is that of J. M. Davis. The clay used is similar to that employed at Oliver's pit described above. It is molded by hand; dried on pallets; and burned in Dutch kilns. A few hundred feet up the track and on the north side of it are two yards operated by the Fulton Brick Company. The brick yard adjoins the clay bank on the west and the material is practically the same as that seen at the Davis place, but the methods used for winning the clay are more improved. After the clay is dug it is loaded on to dumping tram-cars and hoisted up to the plant. There it is put through a pair of rolls and passes from these into a Freese side-cut auger machine. While the clay

is not apparently a difficult one to work, still the lumps of bluish gray clay are not thoroughly broken and they show in the finished product. The material is one which also flows very smoothly through the die of the machine.

The clay is taken from the machine to drying tunnels which are steam heated and passes through these in 38 to 40 hours. The burning is done in Dutch kilns. It is quite evident from the results obtained that this clay is not one which will stand rapid drying in the tunnel, for such treatment results in many cracked bricks. In the burning of the ware it was noticed that in several of the kilns the two courses above the arches were nearly vitrified, while the others were by no means so.

The dark-colored clays, similar to those described from south of Chester, outcrop at several points around the base of Government hill, especially along the Government road leading down from the top of the hill, but in nearly every instance they are covered with too much overburden to permit of their being profitably worked.

SUMMARY.—It may be well to make a comparative summary of the clays found in the Richmond area. Those found near the city, and those which are worked at Manchester, Fulton, and near the reservoir, are to be classed as good common-brick clays, which burn to a good color, and also make a fair grade of front brick when repressed. They are too gritty and stony as well as too irregular in their character to be used for drain tile, hollow blocks or red earthenware. The methods used for working them are usually crude, and therefore the yards are of limited capacity. The manufacturers claim, however, that owing to difficulties with labor, it is impracticable to use more improved methods, such as machine molding. Some also maintain that the hand-molded brick sells better on the local market.

The clays found at Fort Lee appear to be less stony and even less sandy than those occurring at Richmond, and they are susceptible of being worked by more improved methods. Of the yards located at Fort Lee one used a soft-mud machine, and another a stiff-mud machine. Even these clays, however, are somewhat siliceous for any use other than brick, although it is probable that drain tile or hollow brick could be made from them.

Apparently the best clay in the Richmond area is that described from near Stagg's Mill on the Williamsburg road. This is more plastic, denser burning and less sandy, than any of the clays now being worked either around Richmond or Fort Lee. The deposit being located so close to the city, as well as close to a railroad line should be investigated by clay manufacturers.

Large areas have already been dug over in the brick making districts around Richmond, because the deposits are comparatively shallow, and the output of the yards has been large. Each manufacturer naturally excavates the clay nearest to his yard first, so that as year after year goes by the pit face recedes, and the clay haul becomes longer and longer. As the city of Richmond and its suburbs are growing, it will not be many years before buildings will encroach on the brick yards, and the latter will have to be moved. Being, as it were, temporarily located, there is therefore not much inducement for establishing an extensive plant.

THE CURLE'S NECK AREA.

About one mile north of Curle's Neck and 6 miles south of Richmond there are a number of exposures of clay along the road, and also on the farm on the west side of the road at a locality pointed out by Mr. A. W. Ball, of Richmond. This material has been usually spoken of as fullers earth, and some sample car-loads have been shipped to cotton oil factories in order to test it for bleaching purposes. The material, however, is very plastic and on inspection one would be likely to form the opinion that it was a clay suitable for the manufacture of some red-burning ware. In fact it is stated that at one time a small stoneware pottery was in operation at this point and there is considerable evidence of this in the numerous fragments of stoneware which are scattered around in the field near the farmhouse. I was not able to find out, however, just what part of the deposit had been used for making the pots and jugs. In order to determine its value the material was examined both as to its burning qualities and also its bleaching properties. Three samples in all were collected. The first of these (Lab. No. 1314) was a so-called pottery clay taken from about one-half way down the gully just west of the barn on the A. W. Ball property and one mile east of Coltman's postoffice. A second sample (Lab. No.

1315) was taken from the head of the gully and was said by Mr. Ball to represent the best grade of the fullers earth to be found on this land.

A third sample (Lab. No. 1316) was collected from an outcrop on the west side of the road just southwest of the barn. As regards their bleaching power, it may be said that, while all three bleached the oil moderately well, neither of them is to be classed as a good grade of fullers earth. In fact their bleaching power was inferior to that of some of the earths found in Georgia. They were then tested in order to determine their value for the manufacture of clay products and the results of these tests are given in parallel columns below.

Number	1314	1315	1316
Color	yellow buff	yellow buff	light gray
Water required	20.9	23.1	24.2
Slaking	mody. fast	mody. fast	mody. fast
Plasticity	good	good	excellent
Grit	little	little	little
Air shrinkage	7.4	7.3	8.6
Average tensile strength	134.8	126.7	135.1

WET-MOLDED BRICKLETS.

	1314	1315	1316
Cone 010			
Fire shrinkage	0	0	0
Color	light red	light red	pink cream
Absorption	17.7	19.5	16.03
Cone 05			
Fire shrinkage	4.7	3	4.3
Color	light red	light red	pink buff
Absorption	10.1	14.8	9.2
Cone 03			
Fire shrinkage	6	4.3	5
Color	light red	light red	buff
Absorption	7.02	13.1	4.7
Cone 1			
Fire shrinkage	8.3	9	6.5
Color	red	red	gray buff
Absorption	1.5	2.5	.09
Cone 3			
Fire shrinkage	7 6	8.6	7
Color	dark red	dark red	gray buff
Absorption	.4	1.01	.07
Cone 5			
Fire shrinkage	beyond vitri.	7	7
Color		gray	drab
Absorption		.70	.14
Cone 8			
Fire shrinkage		7	beyond vit.
Color		dk. red brown	
Absorption		.55	9

DRY-PRESS BRICKLETS

Cone 1		
Fire shrinkage	7	8
Color	light red	light red
Cone 3		
Fire shrinkage		8
Color		dark brown
Absorption		5.93

Chemical analyses of samples of these earths yielded the following results:

Lab. No.	1314	1315	1316
Silica (SiO_2)	65.97	63.82	66.01
Alumina (Al_2O_3)	17.38	20.44	20.77
Ferric oxide (Fe_2O_3)	6.74	6.32	3.59
Lime (CaO)	1.16	.22	.92
Magnesia (MgO)	.17	.11	.11
Potash (K_2O)	2.46	2.72	2.52
Soda (Na_2O)	.93	.93	.74
Titanic oxide (TiO_2)	1.04	tr.	.50
Loss on ignition	4.10	5.41	4.82
	99.95	99.97	99.98
Total fluxes	11.46	10.30	7.88

Number 1314, the so-called pottery clay, is a red-burning clay of good plasticity which becomes steel-hard at cone 05. The color does not deepen appreciably until cone 1, at which temperature it makes a pretty dense body and is almost vitrified. At cone 3 the body is also dense but the clay is beyond vitrification, while at cone 8 it has reached the beginning of viscosity. The qualities shown by this clay would seem to warrant its being tested on a larger scale for the manufacture of paving brick or perhaps even common stoneware.

Number 1315. This clay is very similar in appearance to No. 1314 and becomes steel-hard at cone 05. It burns red but the color deepens appreciably at cone 1 and the clay does not appear to be really vitrified until cone 3. The chances are that it might serve for making paving brick for light traffic and perhaps even common stoneware.

Number 1316 burns steel-hard at cone 05, and gives an excellent buff color at that cone. In fact at that temperature it would do for buff pressed brick but even if heated above that cone the color is not at all unpleasing. It appears to be vitrified at cone 5 and at cone 8 is very close to viscosity. Its lighter burning character is due to the smaller percentage of iron oxide which it contains.

CHESTERFIELD COUNTY.

THE CHESTER AREA.

There are no brick yards in operation at this locality, but a number of outcrops of clay are to be seen in the railroad and trolley road cuts in the vicinity. None of them, however, are suited to the manufacture of brick. About two miles south of Chester along the Atlantic Coast-Line Railway there are several cuts, which show outcrops of a sandy, bluish, fossiliferous clay. The material is not uniform in character, certain layers being highly fossiliferous, others very sandy, and still others very plastic. The exact thickness of the deposit is not known, but from the exposures it is evidently not less than thirty feet thick. No attempts have been made to utilize it. Since there is a large amount of the clay at this locality, and the same material is found outcropping around Richmond, it was thought desirable to look into its properties. These were as follows: The color of the moist clay (Lab. No. 1305) is gray black, indicating a considerable quantity of organic matter. It slakes fast, and worked up with 25.3 per cent. water to a somewhat gritty mass of low plasticity, whose air shrinkage was 9.3 per cent., and whose average tensile strength was 177.3 pounds per square inch. In burning it behaved as follows:

WET-MOLDED BRICKLETS.

Cone	*010*	*05*	*03*	*1*	*3*
Fire shrinkage	0	1.3	1.6	2 3	viscous
Color	light red	light red	red	red	
Absorption	18.2	14.2	12	7.54	

The material does not burn steel-hard until cone 1, and has to be carefully burned to prevent black cores forming.

Its chemical composition was as follows:

Silica (SiO_2)	69.74
Alumnia (Al_2O_3)	12.64
Ferric oxide (Fe_2O_3)	6.00
Ferrous oxide (FeO)	1.00
Lime (CaO)	1.46
Magnesia (MgO)	1.18
Potash (K_2O)	2.54
Soda (Na_2O)	.92
Titanic oxide (TiO_2)	.06
Water and organic matter	4.41
	99.55
Total fluxes	13.10

The general characteristics of the clay may therefore be summed up as follows: Red burning, low fire shrinkage, and low fusibility. Difficult to burn. It is not to be recommended for anything but common brick, and even for this purpose it should be avoided if something better can be found.

THE BERMUDA HUNDRED AREA.

Much clay is exposed at a point along the railroad from Chester to Bermuda Hundred and about 1 mile from the railroad station at the latter locality. The same material is also seen in the gullies in the neighboring fields. This clay is at the same level as that which is worked at Broadway on the Appomattox and it is probable that the deposit extends in that direction, but they do not belong to the same formation.

The exposures in the railroad cut show a thickness of not less than ten feet, and Mr. Strothers, of Chester, claims that a thickness of 49 feet was proved by boring in one place. Although the clay along the railroad track does not show much variation on inspection, it is stated that at the northeastern end is brick clay, while at the southeastern end it is tile clay. A sample of the latter (Lab. No. 1306) was tested with the following results: Color, yellow buff; slaking, fast; water required, 29.7 per cent.; plasticity, good; grit, very fine; air shrinkage, 8.6 per cent.; average tensile strength, 148.8 pounds per square inch. In burning it behaved as follows:

WET-MOLDED BRICKLETS.

Cone	*010*	*05*	*03*	*1*	*3*	*5*	*8*
Fire shrinkage	.3	5 7	7	10.7	10.3	4 6	6.6
Color	lt. red	lt. red	lt. red	dk. red	dk. red	dk. red	dk. red
Absorption	22.04	12.9	8.7	.12	.11	2.1	1.39

DRY-PRESS BRICKLETS.

Cone	*1*	*3*
Fire shrinkage	9	9
Color	lt. red	lt. red
Absorption		6. 8

The clay burned steel-hard at cone 03. It burned to a good red up to cone 03 but above this began to darken appreciably, and at cone 5 had gotten beyond vitrification.

The chemical composition was:

Silica (SiO_2)	61.83
Alumina (Al_2O_3)	21.26
Iron oxide (Fe_2O_3)	6.85
Lime (CaO)	.38
Magnesia (MgO)	.78
Potash (K_2O)	2.44
Soda (Na_2O)	1.01
Titanic oxide (TiO_2)	.08
Ignition	5.32
	99.95
Total fluxes	11.46

Judging from the dense body of this material it would be worth experimenting with for paving brick, or perhaps pipe. The most serious objection to it is its high air and fire shrinkage.

This clay has been dug and shipped, occasionally, to the works of the Powhatan Clay Manufacturing Company, at Clayville, near Richmond.

DINWIDDIE COUNTY.

THE PETERSBURG AREA.

There are three yards in operation near Petersburg. Two of these, operated, respectively, by W. R. Turner, and Brister and Harrison, are located in Ettricks, across the river from Petersburg; the third, that of the Chesterfield Brick Company, is situated about two miles from Petersburg near the line of the Petersburg-Richmond trolley road.

At the yard of W. R. Turner, the clay (Pl. XIII, Fig. 2.) which is covered by a foot of sand, runs from 15 to 20 feet deep. It is mottled, red, yellow, brown and whitish, and there is also some variation in the other physical properties of the clay. It is therefore necessary to use the run of the bank, as one part, if used alone, laminates too much, or another portion, if used alone, is too sandy, etc. The clay is underlain by sand.

The properties of the run of the bank (Lab. No. 1331) were as follows: Color, when moist, brown buff; water required, 23.1; slaking, slow; plasticity, excellent; grit, little; air shrinkage, 8 per cent.; average tensile strength, 135.5 pounds per square inch.

In burning it behaved as follows:

WET-MOLDED BRICKLETS.

Cone	*010*	*05*	*03*	*1*	*3*	*5*	*8*
Fire shrinkage	.3	2	3.6	4.6	5	7.6	6.3
Color.	lt. red	lt. red	lt. red	red	red	dk. red	dk. red
Absorption.	17.09	15. 30	11.80	7.8	8.7	3	1.3

DRY-PRESS BRICKLETS.

Cone	1	3
Fire shrinkage	4	4
Color	lt. red	lt. red
Absorption		11.78

The chemical analysis showed:

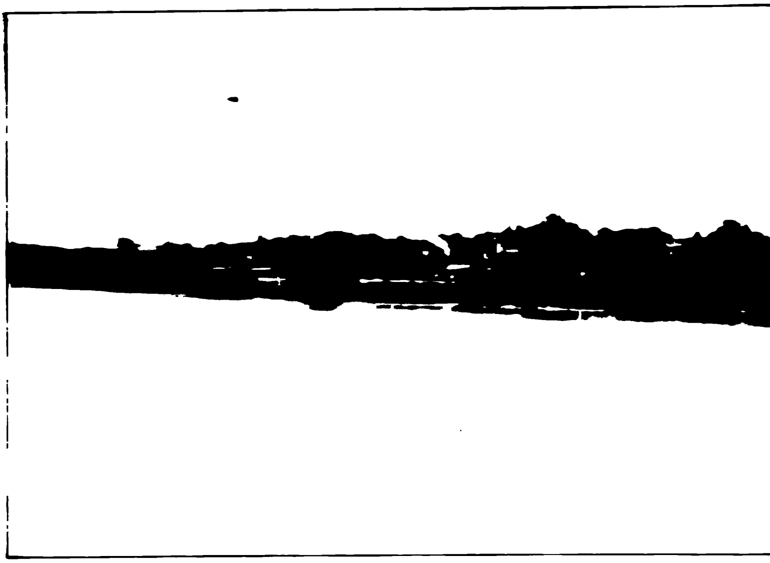
Silica (SiO_2)	61.35
Alumina (Al_2O_3)	19.70
Ferric oxide (Fe_2O_3)	7.10
Lime (CaO)	.67
Magnesia (MgO)	.34
Potash (K_2O)	2.38
Soda (Na_2O)	1.11
Titanic oxide (TiO_2)	.06
Ignition	7.25
	99.96
Total fluxes	11.60

This clay burns to an excellent red color which is rather light up to cone 03, but at cone 1 is much richer, and if burned for front brick at this cone would probably yield an excellent product. The clay burns steel-hard at cone 1, and vitrifies a little above cone 5. At cone 8 it was not yet viscous. The air shrinkage is somewhat higher than is desirable, but this can be regulated by using a larger proportion of the sandy clay. The clay would no doubt work for dry-press brick and if hard burned might even serve for paving purposes under light traffic.

At present it is used only for common building brick. The run of the bank is tempered in a pugmill, and molded in an auger side cut machine. (Pl. VII.). The bricks are dried under sheds, and the burning done in Dutch kilns. Some repressing is done in a hand-power machine.

Brister and Harrison's yard adjoins Turner's on the east, and the clay deposits at the two yards are undoubtedly continuous. The overburden is not more than one foot thick and the clay varies from 10 to 20 feet in thickness, resting on an uneven bottom of sand and gravel. As the clay in this bank varies much like that in the preceding, it is equally important to mix it. If properly mixed and pugged it works well on a stiff-mud machine.

The clay is molded on a plunger stiff-mud machine, dried on pallets and burned in scove kilns.



A. General view of Keeler's brick yard at Broadway on the Appomattox River. The clay bank lies at top of bluff to rear of yard.

B. Keeler's clay bank at Broadway on the Appomattox River.

The type of clay used at Turner's, and Brister and Harrison's yards is not an uncommon one around Petersburg, and a number of exposures of it are to be found, especially in the cuts along the Seaboard Air-Line Railway, but much of the area around the city is underlain by a heavy bed of sand and gravel.

At the works of the Chesterfield Brick Company, whose location is mentioned above, the material used is a sandy surface loam, of a type not uncommon in this vicinity, and which is perhaps of residual character, having been derived from the underlying granites. The clay is very shallow and suitable only for common brick. At present it is being worked by the stiff-mud process, but the company is abandoning the use of this clay, and intends working a more plastic material which will give better results.

The local contractors state that the supply of bricks from the yards around Petersburg is entirely insufficient to meet the demand in that city.

PRINCE GEORGE COUNTY.

THE BROADWAY AREA.

The only brick yard in operation at this locality is that of Keeler & Son, which is located immediately at the foot of the bluff along the Appomattox river. The clay deposit lies about 75 feet above the river and the clay is being dug at a point in the terrace about 300 feet south of the yard. It is a tough, mottled material with a thickness of at least 15 feet, the upper two feet of which are weathered. Overlying this is about 18 inches of gravelly sand similar to that which occurs immediately under the surface throughout this region on both sides of the river. The clay is underlain by a coarse, gravelly sand which extends down to the river level and probably below it. The pit, however, is not over 7 feet deep (Pl. XI, Fig. 2.). The physical and chemical properties of the clay (Lab. No. 1307) are as follows: Color, moist, yellow buff; slaking, slow; water required, 24.6; plasticity, good; grit, not excessive; air shrinkage, 9 per cent.; average tensile strength, 138.1 pounds per square inch. In burning the clay behaved as follows:

WET-MOLDED BRICKLETS

Cone	*010*	*05*	*03*	*1*	*3*	*5*	*8*
Fire shrinkage	.3	5	6 3	8	9.3	7	7.6
Color	lt. red	lt. red	lt. red	red	dk. red	red. gr.	red br.
Absorption	17.9	10.40	7.3	1.7	.8	1.7	.50

DRY-PRESS BRICKLETS.

Cone	*1*	*3*
Fire shrinkage	8	8
Color	red	red
Absorption		10.17

The clay burns steel-hard at cone 05 and at either this temperature or cone 03 it makes an excellent red brick. I doubt, however, if even cone 05 is reached in burning the product. If burned to this cone, or, better still, to cone 1, the material would probably make a good pressed brick.

The chemical composition is:

Silica (SiO_2)	59.59
Alumina (Al_2O_3)	21.10
Ferric oxide (Fe_2O_3)	8.07
Lime (CaO)	.20
Magnesia (MgO)	.76
Potash (K_2O)	2.38
Soda (Na_2O)	1.06
Titanic oxide (TiO_2)	.12
Loss on ignition	6.67
	99.95
Total fluxes	12.47

This is an excellent red-burning clay which could probably be used for making front as well as common brick, provided it is thoroughly pugged. Although it burns to a good hard body, still, at the same temperatures, the product is not as dense as that tested from near Bermuda Hundred (Lab. No. 1306) or that tested from 6 miles south of Richmond (Lab. Nos. 1314 and 1316). At the present time it is utilized for making common brick and the run of the bank is used, leaving out the overburden of gravelly sand. The clay is loaded onto tram-cars, drawn to the edge of the terrace, and then slid down a chute to the rolls. From these it passes to a side-cut stiff-mud machine. The clay, owing to its good plasticity, seems to flow very rapidly from the die. Drying is done by what is known as the Scott system. This consists in loading the freshly molded brick onto cars, the platform of which is separate from the trucks. These cars are run in under long drying

sheds similar to those shown in Pl. XI, Fig. I., and the platforms carrying the bricks are deposited on separate racks. In order to prevent the clay from drying too fast and cracking, the sides of the racks are protected from the wind by canvas curtains. The bricks are burned in Dutch kilns and the product is shipped by boat, most of it going to Petersburg.

THE CITY POINT AREA.

The Pleistocene clays outcrop in the bluff along the James river, about 1-8 mile south of City Point landing. Their distribution is evidently irregular, for in the first cut of the railroad after leaving City Point, there is nothing but sand exposed, although the bottom of the cut is not as high as the upper part of the clay along the river shore. I was informed that borings made to the south of the railroad cut had revealed the presence of the clay under the surface sand. Along the shore the clay is not less than 20 feet thick, but it contains occasional streaks of sand. There is also about four feet of sandy overburden. No brickyard is located at this point, although the deposit is at the water's edge and the product could be easily shipped. Occasional car-load lots have, however, been dug and shipped to the smoking pipe factory at Pamplin City. As for this line of ware, a small quantity of clay will go a long way, as the amount that has been dug has produced but little impression.

The characters of the clay (Lab. No.1339) are as follows: Color, when moist, brown buff; water required, 20.3 per cent.; slaking, slow; plasticity, excellent; grit, much; air shrinkage, 7.6 per cent.; average tensile strength, 155 pounds per square inch. In burning it behaved as follows:

WET-MOLDED BRICKLETS.

Cone	*010*	*05*	*03*	*1*	*3*	*5*	*8*
Fire shrinkage	.6	3.3	4	6	6.3	6.6	6.6
Color	lt. red	lt. red	lt. red	red	dk. red	dk. red	dk. red
Absorption	17.2	11.5	10.05	4.6	2.7	1.3	1.52

The chemical composition of this clay is shown in the following analysis:

Silica (SiO_2)	61.06
Alumina (Al_2O_3)	19.61
Ferric oxide (Fe_2O_3)	7.03
Lime (CaO)	.77
Magnesia (MgO)	.09
Potash (K_2O)	2.34
Soda (Na_2O)	1.01
Titanic oxide (TiO_2)	.16
Ignition	7.76
	99.83
Total fluxes	11.24

This clay burns steel-hard at cone 05, and yields an excellent red color which it maintains up to cone 03, but above that the color deepens appreciably. It is not as fine grained a clay as that found in the same formation near Bermuda Hundred, nor is it as sandy as that at Broadway. The main advantage of it is, that it is conveniently located for shipment by rail, an advantage not possessed by most deposits along the James river.

CHARLES CITY COUNTY.

THE STURGEON POINT AREA.

W. C. Mayo & Sons operate a common-brick yard at this locality. The plant is located along the river edge at the base of the bluff, while the clay is obtained from near the top of the bluff. The section at this point involves:

Loam	1 to 2 ft.
Clay	7 to 8 ft.
Sand	2 ft.
Mottled clay with iron streaks	9 ft.
Sand	20 to 30 ft.
Blue Clay	3 ft.+

The sand mentioned in the lower part of the section extends down to the river's edge, and at that point it is underlain by a bed of dark bluish gray, highly plastic clay which is about three feet in thickness. The upper layer of clay was formerly worked and a considerable quantity of it has been dug. It was found, however, that it was so variable in its character and burning qualities that it was undesirable to use it, and consequently the raw material for the yard is now taken from the middle clay bed given in the section which yields a more uniform product. The variation in character of the upper clay has been referred to and the tests given. The properties of the lower clay (Lab. No. 1311) are as follows:

Color, yellow buff; water required, 23.1; slaking, moderately fast; plasticity, good; grit, mostly fine; air shrinkage, 7.6 per cent.; average tensile strength, 122.6 pounds per square inch.

In burning the material behaved as follows:

WET-MOLDED BRICKLETS.

Cone	*010*	*05*	*03*	*1*	*3*	*5*	*8*
Fire shrinkage	0	2.3	3	5.6	7	5.3	5.6
Color	lt. red	lt. red	red	red	dk. red	dk. red	dk. red
Absorption	16.8	11.9	8.2	3.9	1.9	1.5	1.07

DRY-PRESS BRICKLETS.

Cone	*1*
Fire shrinkage	3
Color	lt. red

The chemical composition of the material was:

Silica (SiO_2)	68.60
Alumina (Al_2O_3)	16.11
Iron oxide (Fe_2O_3)	6.41
Lime (CaO)	.75
Magnesia (MgO)	.32
Potash (K_2O)	2.35
Soda (Na_2O)	.71
Titanic oxide (TiO_2)	.16
Loss on ignition	4.53
	99.94
Total fluxes	10.54

This clay which becomes steel-hard at cone 05 burns to a rather light red up to cone 03, but at cone 1 it yields a very rich red. It appears to vitrify at a rather low temperature, namely, cone 3, and yet on account of the fine grit it contains, it does not give as dense a body as some of the other clays tested from this formation. At cone 8 it was almost viscous. It is claimed that this deposit of clay extends more or less continuously for at least 12 miles back from the river. In making the clay into brick the run of the bank is used. The material is put through a pugmill and molded in an end-cut auger machine. The bricks are dried in a steam drier, this operation taking about 36 hours. The burning is done in Dutch kilns, and there is said to be 10 inches settle in 46 courses.

The bluish gray clay which outcrops along the river's edge is not more than 3 feet thick and it would probably be difficult to mine, but since the bed is quite persistent and there is a possibility of its outcropping at other points, it was deemed advisable to test a sample of it which was done with the following results:

Color, when moist, bluish-gray; water required, 30.2; slaking, moderately fast; plasticity, fair; grit, some; air shrinkage, 8 per cent.; average tensile strength, 118.7 pounds.

In burning it behaved as follows:

WET-MOLDED BRICKLETS.

Cone	010	05	03	1	3	5	8
Fire shrinkage	.3	2	5.3	8.3	8.3	8.6	7
Color	red	lt. red	lt. red	dk. red	dk. red	dk. red	dk. red
Absorption	20.54	15.9	9.81	2.80	1.5	.15	.04

A chemical analysis of this yielded the following results:

Silica (SiO_2)	61.21
Alumina (Al_2O_3)	20.82
Ferric oxide (Fe_2O_3)	5.81
Lime (CaO)	.57
Magnesia (MgO)	.75
Potash (K_2O)	2.57
Soda (Na_2O)	.73
Titanic oxide (TiO_2)	tr.
Loss on ignition	7.49
	99.95
Total fluxes	10.43

This material is a red-burning clay which burns to a good color and becomes steel-hard at cone 03. It is well vitrified at cone 5, and viscosity has just begun at cone 8. The material would no doubt work for the manufacture of common red earthenware, but cannot be recommended for anything better. The overburden immediately at Sturgeon Point is too thick to permit of the clay being worked at that point. It is possible, however, that the same bed could be found at some other point where there would be less stripping to remove.

THE OLDFIELD AREA.

This locality lies about 4 miles south of Sturgeon Point and on the same side of the river. There is one yard in operation here, namely, that of the Oldfield Brick and Tile Company (Pl. XII, Fig. 1.), which is engaged in the manufacture of common brick. The clay here, as at Sturgeon Point, underlies the terrace which borders the river (Pl. XIII, Fig. 2.), and the brick yard itself is located at the base of the terrace escarpment on the river's edge. It may be said that the materials underlying the terrace consist of dense or alterating beds of sand and clay overburden, and an upper bed of loamy clay underlain

A. General view of Oldfield Brick Co.'s Plant, Oldfield, on James River. Clay pit at rear of yard.

B. Clay pit of Oldfield Brick Co. The clay underlies terrace bordering river.

by a siliceous clay, which weathers to a whitish color and contains many cylindrical limonite concretions. The upper bed has an average thickness of about 3 feet, and this is first removed and utilized for the manufacture of common brick. The under bed seems to be variable in its thickness but where best exposed at the south side of the deposit and nearest to the yard the thickness is at least 7 feet. It is underlain by a tough sandy clay which is not used and which passes downward into a bed of loamy sand containing streaks of pebbles. The two kinds of clay are worked separately, the upper clay being used for common brick, and the lower clay, with the limonite concretions, known as the tile clay, being used for tile or extra hard brick termed paving brick. A sample of each of these was tested and the tests of the two are given in parallel columns, No. 1 being the brick clay, and No. 2 the so-called tile clay.

Lab. No.	1313	1312
Color	buff	gray
Water required	23.1	20.3
Slaking	mody. fast	slow
Plasticity	good	good
Grit	little	much
Air shrinkage	8.6	7.6
Average tensile strength	191	111.5
Cone 010		
Fire shrinkage	.3	0
Color	light red	pink buff
Absorption	17.5	16.3
Cone 05		
Fire shrinkage	1.6	1.6
Color	light red	pink buff
Absorption	14.8	15.04
Cone 03		
Fire shrinkage	4	2
Color	light red	pink buff
Absorption	9.6	13.6
Cone 1		
Fire shrinkage	6 3	3.6
Color	red	yellow red
Absorption	5.5	7.2
Cone 3		
Fire shrinkage	7	6
Color	red	pink buff
Absorption	4.9	3.9
Cone 5		
Fire shrinkage	7.6	6.6
Color	dark green	gray
Ab-orption	1.68	1.08
Cone 8		
Fire shrinkage	5	7.3
Color	drab	drab
Absorption	1.10	1.57

DRY-PRESS BRICKLETS

Cone 1		
Fire shrinkage	4	3
Color	light red	gray buff
Absorption		
Cone 3		
Fire shrinkage		3
Color		light pink
Absorption		15 14

A chemical analysis made of each of these clays yielded the following results:

	1313	1312
Silica (SiO_2)	68.97	73.84
Alumina (Al_2O_3)	16.51	15.08
Ferric oxide (Fe_2O_3)	4.22	3.39
Lime (CaO)	.44	.62
Magnesia (MgO)	.05	.12
Potash (K_2O)	2.59	2.17
Soda (Na_2O)	.56	.71
Titanic oxide (TiO_2)	1.28	1.22
Loss on ignition	5.34	2.81
	99.96	99.96
Total fluxes	7.86	7.01

No. 1313 at low temperatures is a rather light-burning brick clay which becomes steel-hard at cone 03. The color does not deepen appreciably up to cone 1. In order to get a good, hard brick it should be burned at cone 05. The clay seems to vitrify about cone 5, giving a good hard body, but at cone 8 it is past vitrification. At cone 5 the body is very dense and appears much like a stoneware body. Its air shrinkage is a little high and its total shrinkage at cone 5 is not any too low.

Number 1312 is a much more sandy clay which does not burn steel-hard until cone 1, and appears to vitrify at cone 8. At that temperature it burned to a very hard dense body, but one which was not as dense as the Bermuda Hundred clay when burned at cone 3. The difference in the sandiness of the clays is brought out quite well by a comparison of the chemical analyses, No. 1312 having much the higher silica percentage. The chemical composition also indicates the red-burning character of the clay, and No. 1312 burns to a lighter color, not because it contains much less iron than No. 1313 but because the iron is not evenly distributed

A. Ferruginous sandy clay, a type not uncommon around Petersburg. Used for common brick making, but of greater value as a moulding sand.

B. General view of Turner's clay pit, Ettricks, near Petersburg. There is practically no overburden.

through the clay; it being present rather in spots. Of these two clays No. 1313 is by far the more preferable for the production of a hard, dense product.

At present the product of the yard consists almost entirely of common brick for which the run of the bank is used. The clay is hauled in cars to the edge of the terrace and dumped into rolls from which it passes into a Chambers end-cut auger machine with a revolving cut off (Pls. V. and VI.). The green bricks are loaded onto cars which are run onto the drying racks where the platform of the cars is left, the Scott system of drying being used. The product is burned in Dutch kilns and most of it is shipped to Norfolk.

GREENESVILLE COUNTY.

THE BELFIELD AREA.

This town, which adjoins the better known one of Emporia, has one yard, whose product consists entirely of common brick, and which is operated by Dr. Wood, of Emporia. The soil is quite sandy around Belfield, and the surface flat, so that there are very few clay exposures. At the brick yard the clay extends nearly to the surface and averages about 5 feet deep, being bottomed on a coarse, whitish sand, which is not mixed in with the clay as it does not seem to improve its quality. The clay (Lab. No. 1333) is a tough brownish material, with comparatively little sand, but much fine grit. It slakes slowly and works up with 24 per cent. of water to a mass of good plasticity, whose air shrinkage was 8.6 per cent. and whose average tensile strength was 132.4 pounds per square inch.

In burning it behaved as follows:

WET-MOLDED BRICKLETS

Cone	*010*	*05*	*03*	*1*	*3*	*5*	*8*
Fire shrinkage	.3	1	2.7	3	3.6	4.3	6
Color	lt. red	lt. red	lt. red	red	dk. red	dk. red	dk. red
Absorption	16.30	13.70	11.90	11.05	9.9	6.20	1.08

DRY-PRESS BRICKLETS.

Cone	*1*	*3*
Fire shrinkage	2	2
Color	red	red
Absorption		17.25

A chemical analysis of this clay gave:

Silica (SiO_2)	67.14
Alumina (Al_2O_3)	16.18
Ferric oxide (Fe_2O_3)	6.21
Lime (CaO)	1.19
Magnesia (MgO)	.11
Potash (K_2O)	1.95
Soda (Na_2O)	1.10
Titanic oxide (TiO_2)	——
Ignition	6.09
	99.97
Total fluxes	10.56

The clay burns to an excellent red color, but contains so much fine grit that even at cone 3 it does not yield a dense brick; indeed it does not show a very low absorption until cone 8, at which point it begins to fuse. It is not to be recommended for anything but common brick.

The clay as it comes from the bank is put through a pug-mill, from which it is fed directly through the die of an auger machine, so that the material does not receive enough pugging. The bricks are piled on cars, which are run onto racks for drying. Sun drying causes the clay to crack. Burning is done in Dutch kilns.

NORFOLK COUNTY.

THE NORFOLK AREA AND VICINITY.

The cities of Norfolk, Portsmouth and Newport News are among the most important in the Coastal Plain area of Virginia, and in all building operations are being carried on quite extensively. There is here consequently a good market for building brick, either common or pressed, and the supply is drawn from a number of points.

There are several yards in the immediate vicinity of these cities which deserve mention. E. W. Face and Son operate a yard on North Avenue, Atlantic City. The raw material is brought from a pit of Pleistocene clay on the Nansemond river, near Suffolk, and in its general character resembles that worked at the brick yards around Suffolk. It is a red-burning clay of excellent plasticity, which yields a good product for structural work. Before molding the clay has a small quantity of fine coal mixed in with it, to help in burning, a practice somewhat unusual in the Coastal Plain area. It is molded on an end-cut auger machine, dried on hot floors,

and burned in up-draft kilns with permanent side walls. The drying takes 48 hours and the burning from eight to ten days. Some repressing is also done. The entire product is disposed of in Norfolk.

The plant of the Builders Supply Company is located on Middle street, Chesterfield Heights. The clay is a light-colored sandy material averaging about 3 1-2 feet in thickness. There are only a few inches of soil over it, and the clay is free from stones or shells.

The brick are molded in an end-cut auger machine, dried in the sun and burned in Dutch kilns. No repressing is done. The product is of a red color and sells on the local market.

G. A. Stephens' brick yard is located on the Princess Anne road near Godfrey Avenue. It is also working a surface clay, which, however, is somewhat different in its appearance from that at the preceding plant. The clay which immediately underlies the soil is a bluish black, very stiff red-burning clay. On account of its plasticity it is necessary to mix some sand with it to make it more easy working as well as to reduce its plasticity. The clay is molded in soft-mud machines, air dried, and burned in up-draft kilns. The product is sold for common brick.

C. H. Phillips and Brothers operate a yard at Hampton, near Newport News, and here a reddish, sandy, surface clay is used, for making common soft-mud brick.

At Morrison, 1 mile north of the station, is the yard of the Booker Brick Company, whose product goes mostly to Norfolk. This is a shallow Pleistocene deposit, 3 or 4 feet in depth and underlain by sand. The material is red-burning and used only for the manufacture of common brick. Its chemical composition is:

Silica (SiO_2)	68.84
Alumina (Al_2O_3)	14.78
Ferric oxide (Fe_2O_3)	3.08
Lime (CaO)	.12
Magnesia (MgO)	.08
Potash (K_2O)	2.32
Soda (Na_2O)	.83
Titanic oxide (TiO_2)	.78
Moisture 110° C.	3.90
Ignition	5.44
	100.17
Total fluxes	6.43

NANSEMOND COUNTY.

THE SUFFOLK AREA.

Four brick yards were visited at this locality, namely, those of the Standard Brick Company, Horrell and Company, Suffolk Clay Company, and West End Company.

The Standard Brick Company's yard is located about one and a half miles south of Suffolk along the Southern Railway. The surrounding region is underlain by a deposit of sand, often of coarse grain and variable thickness. Some of it might serve for molding sand, and much of it no doubt would answer for the manufacture of sand-lime brick. If the region between Suffolk and the brick works is underlain by clay it could only be determined by boring or test-pits. At the pit of the Standard Brick Company (Pl. XIV, Fig. 1.) there is a little stripping to be done before the clay is reached. The bed has a depth of about 6 feet, the lower two to three feet being a dark bluish gray and the upper half discolored by weathering. At the time of the writer's visit only the lower clay was being used. This burns to a harder brick but has a higher shrinkage than the top clay. The material is loaded onto cars and hoisted up an incline to the works. Then it passes through a pair of rolls to the pugmill which tempers it for the end-cut auger machine. The clay runs through the die with remarkable smoothness. Drying is done in tunnels, and here the clay shows a tendency to crack badly unless properly handled. It is possible that an admixture of the top clay would prevent this. The bricks are burned either in circular down-draft kilns or in up-draft kilns with permanent side walls. The bricks should be burned harder than they are being fired to insure better results.

The properties of the blue clay (Lab. No. 1343) are as follows: Slaking, slow; water required, 22; plasticity, excellent; grit, much; air shrinkage, 8.6; average tensile strength, 144.9 pounds per square inch.

WET-MOLDED BRICKLETS.

Cone	010	05	03	1	3	5	8
Fire shrinkage	sl. swell.	1.6	1.6	1.6	2.3	2.3	3.3
Color	pink	pink buff	pink buff	lt. red	lt. red	lt. red	light brown
Absorption	14.6	13.6	12.6	10.7	7.9	7.01	3.6

A. Clay bank of Standard Brick Co., near Suffolk.

B. Bluffs of diatomaceous earth (Miocene age) along Rappahannock River, southeast of Wilmont.

DRY-PRESS BRICKLETS.

Cone	*1*
Fire shrinkage	2
Color	pink

The chemical composition is:

Silica (SiO_2)	75.79
Alumina (Al_2O_3)	14.85
Ferric oxide (Fe_2O_3)	3.17
Lime (CaO)	.04
Magnesia (MgO)	.08
Potash (K_2O)	.75
Soda (Na_2O)	.22
Titanic oxide (TiO_2)	trace
Ignition	5.06
	99.96
Total fluxes	4.26

The clay burns steel-hard at cone 03 but does not yield a very deep-colored product. It cannot be stated in advance, without practical trials, whether the clay would yield a good pressed brick.

The yards of the Suffolk Clay Company, and the West End Company are located west of Suffolk and on adjoining properties; in fact the clay deposits worked at the two are probably continuous at the yard of the West End Company. The clay deposit varies from 5 to 15 feet in thickness with very little overburden. It is underlain by a bed of black sand, which in places is quite clayey, but is not mixed with the brick clay. The clay bed has been traced horizontally for at least 200 yards, and contains few stones. No sample of this was tested. The clay is worked up in a stiff-mud machine, and dried in 24 hours in steam heated tunnels.

At the bank of the Suffolk Clay Company, the section shows:

Top soil	1 ft.
Yellow clay	3 ft.
Blue clay, lower foot sandy	9 ft.
Limonite sand	1 ft.
Sand	8 ft.
Blue marl	20 ft.

For brick making the run of the bank, including the sand layer, is used. The blue clay is not safe to use alone by any process of wet-molding, but it gives a harder, denser body. The properties of the brick mixture (Lab. No. 1345) and the blue clay (Lab. No. 1344) are given below:

12

Laboratory No.	1345	1344
Color moist	buff	blue
Water required	26.4	31.9
Slaking	slow	slow
Plasticity	good	excel't
Grit	some	little
Air shrinkage	10.3	11.6
Average tensile strength	142.5	143.8
WET-MOLDED BRICKLETS.		
Cone 010		
Fire shrinkage	.6	1.3
Color	pink	pink
Absorption	15.4	16.9
Cone 05		
Fire shrinkage	3	4
Color	lt. red	pink
Absorption	10.6	8.87
Cone 03		
Fire shrinkage	3.6	5.6
Color	red	lt. red
Absorption	7.5	6.11
Cone 1		
Fire shrinkage	6.6	7
Color	red	lt. br.
Absorption	2.6	1.50
Cone 3		
Fire shrinkage	7.3	7.6
Color	dk. red	drab
Absorption	1.04	.20
Cone 5		
Fire shrinkage	7	beg. vit.
Color	gray	gray
Absorption	.60	1.2
Cone 8		
Fire shrinkage	5	
Color	red gray	
Absorption	.02	
DRY-PRESS BRICKLETS		
Cone 1		
Fire shrinkage	6	7
Color	lt red	lt. br.

Chemical analyses of these two clays gave:

	1345	1344
Silica (SiO_2)	65.55	64.39
Alumina (Al_2O_3)	18.13	20.49
Ferric oxide (Fe_2O_3)	5.29	4.40
Lime (CaO)	.39	.17
Magnesia (MgO)	.51	.91
Potash (K_2O)	1.82	2.31
Soda (Na_2O)	.33	.54
Titanic oxide (TiO_2)	1.95	.08
Ignition	5.98	6.66
	99.95	99.95
Total fluxes	8.34	8.33

A. Diatomaceous earth overlain by Pleistocene clay at Wilmont.

B. General view of brick plant at Wilmont.

Number 1345 is a very hard-burning clay and becomes steel-hard even at cone 05. It burns to a light red up to cone 03, and deep but good red at cone 1. It is very plastic, and has a high air shrinkage but the fire shrinkage is low. It works well in a stiff-mud machine. It appears to be completely vitrified at about cone 4, and at cone 8 it is nearly viscous. The clay should be fired slowly in the early stages of burning on account of the carbonaceous matter which it contains. It seems probable that this clay could be used for pressed brick. The difference in character between this clay and the blue clay alone is well brought out by the physical tests given above.

Number 1344 also burns steel-hard at cone 05. It is practically vitrified at cone 1, and were it not for its high total shrinkage, it could probably be used for paving brick. It might also serve for common stoneware. This was one of the most dense-burning clays of the entire series tested.

The method of manufacture employed at the Suffolk Clay Company's yard consisted in feeding the clay first into rolls, from which it passed to a double pug-mill. The brick were molded in a Fate auger machine, with end-cut table. Drying was done in tunnels heated by coal, and required 48 hours to prevent cracking. The bricks were burned in up-draft kilns with permanent side walls.

Horrell and Company use a mottled clay, similar to that dug along the Nansemond river near Suffolk. It is dug in the fall and piled up through the winter. The molding is done on a small auger machine, drying on pallets and burning in scove kilns. The clay burns to an excellent color.

THE CLAY WORKING INDUSTRY OF THE VIRGINIA COASTAL PLAIN AREA AND ITS FUTURE TENDENCY.

Having given in some detail the properties of the commercially valuable clays which are found in the Coastal Plain region of Virginia, it seems proper to say a few words regarding the present condition of the clay-working industry in this region, and its future development.

As already noted there are five important brick making districts in the Tidewater belt which, in the order of their importance, are: Alexandria, Richmond, Norfolk, Suffolk, and Petersburg. In addition to these there are a number of other places at which one, or at most two, usually small plants are located.

At nearly every one of these localities the product consists exclusively of common red brick. Some yards are equipped with a hand-power repress, and when the occasion demands, repressed brick are supplied, but throughout this entire area, there is only one company which makes a specialty of pressed brick, namely, the Hydraulic Pressed Brick Company at Alexandria. This firm has taken the trouble to separate the different layers of the deposit near its yard, recognizing that they do not all burn to the same color.

In addition to building brick a few drain tiles are made, some hollow brick and boiler brick at one locality, Wilmont.

This represents the range of products now being turned out in the Coastal Plain belt of Virginia, and naturally leads to the conclusion that there is ample room for development, provided the clays are suitable.

From the experiments made in the laboratory the writer feels convinced that the Coastal Plain clays have not yet been put to their fullest use. Some of these clays could be made into a hard brick suitable for use under at least light traffic; not a few could be turned into red earthenware, and many would undoubtedly work up into dry-press brick. The manufacture of hollow brick should also be considered in connection with the expansion of the clay-working industry in this area. There seem strong possibilities too in the buff-burning Eocene clays already referred to as occurring northeast of Fredericksburg.

As regards the methods of manufacture now employed at the active brick yards, it cannot be said that they are in all cases modern. The old method of hand molding, sun drying and scove kilns, is still adhered to, where the clay would stand improved treatment. Curiously enough, where machines are employed for molding, stiff-mud machines are more often seen than soft-mud ones. In such cases the pugging is incomplete, and the drying method not as improved as the molding.

It is true that with the methods now being employed, a good common brick is being turned out; but, with better methods the capacity of the yard could be increased and the cost of production lowered.

Building operations and town or city improvements are going on in many of the towns and cities of eastern Virginia, and there is no good reason why the clays should not be converted into products to be used in these improvements.

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UNIVERSITY OF VIRGINIA

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DIRECTOR

Bulletin No. II—A

THE

Cement Resources of Virginia

WEST OF THE BLUE RIDGE

BY

RAY S. BASSLER, PH. D.

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Cement Resources of Virginia

WEST OF THE BLUE RIDGE

BY

RAY S. BASSLER, PH. D.
Curator, Division of Invertebrate Paleontology
United States National Museum,
Special Geologist, Virginia Geological Survey

WITH AN

INTRODUCTORY CHAPTER
ON THE MATERIALS AND MANUFACTURE
OF HYDRAULIC CEMENTS

BY

EDWIN C. ECKEL, C. E.
Formerly Assistant Geologist, United States Geological Survey.

CHARLOTTESVILLE
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1909

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STATE GEOLOGICAL COMMISSION

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VIRGINIA GEOLOGICAL SURVEY,
UNIVERSITY OF VIRGINIA,
CHARLOTTESVILLE, October 1, 1909.

To His Excellency, Hon. Claude A. Swanson, Governor of Virginia, and Chairman of the State Geological Commission:

Sir:—I have the honor to transmit herewith for publication, as Bulletin No. II-A of the Virginia Geological Survey Series of Reports, a report on the "Cement Resources of Virginia West of the Blue Ridge", by Dr. R. S. Bassler, Curator of Invertebrate Paleontology in the United States National Museum, and Special Geologist on this Survey.

This report has been prepared in coöperation with the United States Geological Survey and the United States National Museum. The field work upon which the report is based has extended over parts of several field seasons, and was completed during the season of 1908.

The remarkable growth of the cement industry in the United States during the last decade still continues, and the increasing demand for cement has resulted in many of the geological surveys, both state and national, investigating areas of cement-making rocks as sources of supply of raw materials for cement manufacture. Investigations by the Virginia Geological Survey demonstrate that Virginia contains extensive areas of raw materials suitable for cement manufacture, equal in value and abundance to those of any other state. Many areas of the raw materials are traversed by lines of railroad, which insure necessary transportation facilities, and they afford desirable mill-sites for the manufacture of cement.

The Mountain province, including the Appalachian (Shenandoah) Valley and the numerous mountains and valleys westward, is the first of the three major provinces in the State to be completed in the investigation of the cement resources. A similar study of the cement-making rocks in the Piedmont and Coastal Plain provinces has been in progress for two field seasons, and upon completion of the field and laboratory investigations there will be issued a report on the raw materials suitable for cement manufacture in these two provinces. The present volume, detailing the results obtained by careful field and laboratory study of the cement-making

rocks of that portion of the State lying west of the Blue Ridge, represents the first comprehensive stratigraphic study of the region as a whole, and it forms a permanent basis for future more detailed studies of the stratigraphy of the region. As such it is a real contribution to the geology of Virginia.

The author shows the prominent sources of cement material in the Appalachian province of the State to be as follows, listed in geologic order:

5. Mississippian (Greenbrier) limestone and (Pennington) shale.
4. Devonian (Helderbergian) limestone and black shale.
3. Silurian (Cayugan) limestone and shale.
2. Ordovician (Trenton, etc.) limestones and shales.
1. Cambrian—impure limestone and shale.

The Ordovician limestones and shales are the most important of these. because of their abundance and usually favorable chemical composition. The Cayugan and Helderbergian limestone (Lewistown) is used in the manufacture of Portland cement in the plant at Craigsville, Augusta county, Virginia. In southwestern Virginia, the Mississippian (Greenbrier) limestone will probably become an important source of cement material.

As the author states, in addition to the description of the character and distribution of the cement materials, this volume is so arranged that it may serve as a preliminary account of the stratigraphy of western Virginia.

Respectfully submitted,

THOMAS LEONARD WATSON,

Director.

INTRODUCTION

This report deals essentially with the limestones and shales of Appalachian Virginia—in other words, with the materials here present which may be used in the manufacture of cement. In the minds of many, the mineral wealth of an area is associated mainly with metallic compounds, and limestone rocks are looked upon as of little value. When, therefore, it is realized how many important industries depend upon limestone, the value to a community of a good deposit may be better appreciated. The cement industry depends upon such materials.

The growth of the cement industry in the United States during the last ten years has been equalled perhaps by that of no other non-metallic structural material. This remarkable growth still persists and bids fair to continue because of the ever increasing building operations of the country. The recognition of cement as a most valuable structural material, and its advantages over many other building materials in the matter of cheapness and durability, will always cause it to be regarded as a staple article of manufacture. A region, therefore, containing the natural materials from which cement can be made, has economic resources which, sooner or later, will prove of great value. In this respect Virginia is preëminent. The Appalachian Valley and the various mountains and valleys westward, a tract 350 or more miles long, and averaging 50 miles in width, contains limestones and shales apparently equal in value and abundance to those of any other region.

The increasing demand for cement has led to the establishment of new mills, and the necessity for more knowledge concerning areas of cement-making rocks. The Federal Geological Survey and the various state surveys, recognizing this necessity, have paid considerable attention to such materials, with the result that the sources of supply in a number of states are now fairly well known. For the state of Virginia, this work was undertaken by the Virginia Geological Survey in coöperation with the U. S. Geological Survey, and completed under the auspices of the State Survey.

The present report is based largely upon field work by the writer during portions of the summers of 1905 and 1906, under the joint auspices of coöperative geologic work in Virginia by the State Board

of Agriculture and the Board of Visitors of the Virginia Polytechnic Institute, the U. S. Geological Survey, and the U. S. National Museum. In the latter part of the field season of 1908, several weeks were devoted particularly to detailed mapping and to a study of the post-Ordovician cement materials, this work being under the direction of the State Geologist. In addition to this field work, Dr. E. O. Ulrich, under whose official direction the Federal Survey's part of the work was undertaken, made detailed sections in Virginia, notably at Strasburg, Pearisburg, and several localities in the southwestern part of the state, in the course of joint studies on Appalachian stratigraphy with the writer. These sections, as arranged and interpreted by the writer, have been included in the present volume.

In the preparation of the maps, free use has been made of the various folios of the U. S. Geological Survey bearing upon this part of Virginia, and of the topographic sheets covering the rest of the western part of the state. Prof. H. D. Campbell, of Washington and Lee University, has contributed photographs as well as notes of localities in the Lexington area, and has generously accorded the writer the benefit of his broad experience in the stratigraphy of western Virginia. Mr. Charles Catlett, of Staunton, Va., has kindly allowed the use of preliminary analyses of the rocks in the vicinity of Harrisonburg and Staunton, Va. The Virginia Portland Cement Company has furnished cuts and notes on the operation of their plant.

The chemical analyses have been made by Mr. J. H. Gibboney, formerly of the Virginia Polytechnic Institute, and Mr. William M. Thornton, Jr., chemist to the Virginia Geological Survey. Mr. Wirt Tassin, formerly of the U. S. National Museum, has kindly allowed the publication of analyses made by him from Ordovician limestones of northwestern Virginia. To give the chemical composition of the rocks as completely as possible, there has also been incorporated in the present work the various analyses made for Professor Rogers over 70 years ago, and published in his "Geology of the Virginias." At that time a good cement rock was judged from its use for the manufacture of natural cement. Such rock contains a considerable percentage of magnesian carbonate, and, as shown by the analyses, Professor Rogers's samples were selected with this in view.

Recent experiments upon the use of high magnesian limestones have shown that it is possible to employ such rock in the manufacture of a high-grade Portland cement. Mr. Richard R. Meade, chemist for the

Dexter Portland Cement Company, at Nazareth, Pa., has invented a process for making cement from limestone containing 5 to 20 per cent. of magnesia, although argillaceous limestone, or "cement rock," as now understood, is a necessary ingredient of the mixture, the magnesian limestone only taking the place of the purer limestone now in use. The principle underlying the use of such limestone consists in the conversion of the magnesia into the oxy-chlorid of magnesia, a compound of great cementing power. To furnish the chlorine, calcium chloride or any other chloride, such as sodium chloride, is added to the mixture at almost any stage in the process of manufacture. Should this process prove a practical success, it would end the necessity for the scarce high-grade limestone and thus cut off a considerable item of expense in manufacture. The cement rock areas of the Appalachian Valley nearly always have deposits of magnesian limestone close at hand, but the purer limestones are infrequent.

Recognizing this possibility, the State Geologist has requested that the dolomitic limestones of the Valley of Virginia, hitherto considered of no use in cement manufacture, be studied and analyzed with as much care as circumstances warranted. However, in the present stage of the investigation, the writer has thought it best to continue regarding limestone, containing more than 5 per cent. of magnesium carbonate, as of no value in the manufacture of Portland cement.

Dr. Thomas L. Watson, State Geologist, has placed at the disposal of the writer every facility for making the present work complete, and grateful acknowledgment is made for this, as well as for helpful advice and suggestions. A number of the illustrations introduced into the present work were furnished by Dr. Watson from his volume on the "Mineral Resources of Virginia."

In order to complete the description of the economic materials of the state, a portion of the present report was published in the volume entitled "Mineral Resources of Virginia," prepared for the Jamestown Exposition. In 1908, with the permission of the State Geologist, a digest of this article was published in "Economic Geology."

With the exception of folio work by the U. S. Geological Survey in the southwestern part of the state, comparatively little has been published upon the detailed stratigraphy of western Virginia. This applies especially to the Cambrian and Ordovician strata, where, until recently, with the exception noted, only two subdivisions, the Shenandoah limestone and Martinsburg shale, have generally been recognized. The economic im-

portance of certain portions of these two larger divisions has made more detailed stratigraphic work not only desirable but necessary, and the writer has attempted to discriminate the formations accordingly. In the discrimination of these formations the criteria relied on are, first, their faunal contents; second, their lithologic peculiarities, and finally such other physical data as are indicated by stratigraphic overlaps and related phenomena.

Again, practically nothing concerning the Paleozoic fossils of Virginia has appeared in the literature, and it therefore became necessary to present some of the faunal evidence employed in the discrimination of the formations. Plates showing a few of the most diagnostic fossils of the various formations have been introduced, and an attempt has been made to illustrate characteristic outcrops of the more important strata, as well as to show the character of the rock itself by views of hand samples. For the various reasons just mentioned, the discussion of the stratigraphy occupies a greater number of pages than is usual in an economic report. Indeed, the writer, in addition to describing the character and distribution of the cement materials, has endeavored to so arrange the present volume that it may serve as a preliminary account of the stratigraphy of western Virginia.

The following chapter on the materials and manufacture of hydraulic cements (pages 5 to 32), prepared and contributed by Mr. E. C. Eckel, has been published in part in his "Cement Materials and Industry of the United States."[a] The matter is so germane to the present bulletin, and so concisely given, that it was thought advisable to publish it in its entirety.

[a]Bull. No. 243, U. S. Geological Survey.

THE MATERIALS AND MANUFACTURE OF HYDRAULIC CEMENTS

BY EDWIN C. ECKEL.[a]

The hydraulic cements are those which set when used under water, though the different kinds differ greatly in the extent to which they possess this property, which is due to the formation during manufacture of compounds of lime with silica, alumina, and iron oxide.

On heating a pure limestone ($CaCO_3$) containing less than, say, 10 per cent. of silica, alumina, and iron oxide together, its carbon dioxide (CO_2) is driven off, leaving more or less pure calcium oxide (CaO) (quick-lime or common lime). If the limestone contains much silica, alumina, or iron oxide, the result is quite different, for various compounds of lime with silica, alumina, etc., will be formed. The burned mass will not slake if water be poured on it, but if ground up finely the resulting powder will be a hydraulic cement.

Three different classes or groups of hydraulic cements exist, and materials for the manufacture of all of these classes occur in Virginia. The three classes are:

1. Natural cements.
2. Portland cements.
3. Puzzolan cements.

Natural cements.—Natural cements are produced by burning a naturally impure limestone, containing from 15 to 40 per cent. of silica, alumina, and iron oxide, at a comparatively low temperature, about that of ordinary lime burning. The operation can therefore be carried on in a kiln closely resembling an ordinary lime kiln. During the burning the carbon dioxide of the limestone is almost entirely driven off, and the lime combines with the silica, alumina, and iron oxide, forming a mass containing silicates, aluminates, and ferrites of lime. If the original limestone contained much magnesium carbonate the burned rock will contain a corresponding amount of magnesia.

[a]For a more detailed discussion see Municipal Engineering, Vol. 24, 1903, pp. 335–336, and Am. Geologist, Vol. 29, 1902, pp. 146–154.

The burned mass will not slack if water be added. It is necessary, therefore, to grind it rather fine. After grinding, if the resulting powder (natural cement) be mixed with water it will harden rapidly. This hardening or setting will also take place under water. Natural cements differ from ordinary limes in two noticeable ways:

(1) The burned mass does not slack on the addition of water.

(2) The powder has hydraulic properties, i. e., if properly prepared, it will set under water.

Natural cements differ from Portland cements in the following important particulars:

(1) Natural cements are not made from carefully prepared and finely ground artificial mixtures, but from natural rock.

(2) Natural cements are burned at a lower temperature than Portland, the mass in the kiln never being heated high enough to even approach the fusing or clinkering point.

(3) Natural cements, after burning and grinding, are usually yellow to brown in color and light in weight, having a specific gravity of 2.7 to 3.1, while Portland cement is commonly blue to gray in color and heavier, its specific gravity ranging from 3 to 3.2.

(4) Natural cements set more rapidly than Portland cement, but do not attain so high tensile strength.

(5) Portland cement is a definite product, its percentage of lime, silica, alumina, and iron oxide varying only between narrow limits, while brands of natural cements vary greatly in composition.

Portland cement.—Portland cement is produced by burning a finely ground artificial mixture containing essentially lime, silica, alumina, and iron oxide in certain definite proportions. Usually this combination is made by mixing limestone or marl with clay or shale, in which case the mixture should contain about three parts of the lime carbonate to one part of the clayey materials. The burning takes place at a high temperature, approaching 3,000° F., and must therefore be carried on in kilns of special design and lining. During the burning, composition of the lime with silica, alumina, and iron oxide takes place. The product of the burning is a semifused mass called "clinker," which consists of silicates, aluminates, and ferrites of lime in certain fairly definite proportions. This clinker must be finely ground. After such grinding, the powder (Portland cement) will set under water.

Puzzolan cements.—The cementing materials included under this name are made by mixing powdered slacked lime with either a volcanic ash or a blast-furnace slag. The product is, therefore, simply a mechanical mixture of two ingredients, as the mixture is not burned at any stage of the process. After mixing, the mixture is finely ground. The resulting powder (puzzolan cement) will set under water.

Puzzolan cements are usually light bluish, and of lower specific gravity and less tensile strength than Portland cement. They are better adapted to use under water than in air, as is explained on later pages.

PORTLAND CEMENT.

The important building material known as Portland cement was first manufactured in England in 1824. Its name is not, as is often supposed, due to the fact that it is manufactured at Portland, England, Portland, Me., or Portland, Oreg.; for it is not now and never has been made at those points. The name "Portland" was applied to this type of cement because after hardening it resembles somewhat a gray limestone extensively quarried at Portland, England, and well known to the English stone trade. The original patents in Portland cement have long since expired, the processes of manufacture are in no way secret, and it may now be manufactured at any point where suitable raw materials are obtainable.

Portland cement is produced by burning a finely ground artificial mixture, consisting essentially of lime, silica, alumina, and iron oxide, in certain definite proportions. Usually this combination is made by mixing limestone or marl with clay or shale, in which case about three times as much of the lime carbonate should be present in the mixture as of the clayey materials. The burning takes place at a high temperature, approaching 3,000° F., and must therefore be carried on in kilns of special design and lining. During the burning, combination of the lime with silica, alumina, and iron oxide takes place. The product of the burning is a semifused mass called clinker, and consists of silicates, aluminates, and ferrites of lime in certain definite proportions. This clinker must be finely ground. After such grinding, the resulting powder is Portland cement.

The finished product is blue to gray in color, has a specific gravity of 3.0 to 3.25, and when mixed with water will harden or set.

The product must be uniform in composition and quality; and as the processes of manufacture involve certain chemical as well as physical

changes, four points may be regarded as of cardinal importance in making Portland cement. These are:

1. The cement mixture must be of the proper chemical and physical composition.

2. The raw materials of which it is composed must be finely ground and intimately mixed before burning.

3. The burning must be conducted at the proper temperature.

4. After burning, the resulting clinker must be finely ground.

The methods of manufacture of Portland cement have been recently described in some detail by the present writer in several reports which are still readily obtainable. Reference should therefore be made to the reports mentioned[a] in case information in regard to manufacturing details is desired. In the present report only such matters as directly concern the question of raw materials will be discussed.

For the purposes of the present report it will be sufficiently accurate to consider that a Portland cement mixture, when ready for burning, will consist of about 75 per cent. of lime carbonate ($CaCO_3$) and 20 per cent. of silica (SiO_2), alumina (Al_2O_3) and iron oxide (Fe_2O_3) together, the remaining 5 per cent. including any magnesium carbonate, sulphur and alkalies that may be present.

The essential elements which enter into this mixture—lime, silica, alumina, and iron—are all abundantly and widely distributed in nature, occurring in different forms in many kinds of rocks. It can therefore be readily seen that, theoretically, a satisfactory Portland cement mixture could be prepared by combining in an almost indefinite number of ways and proportions many possible raw materials. Obviously, too, we might expect to find perfect gradations in the *artificialness* of the mixture, varying from one extreme where a natural rock of absolutely correct composition was used, to the other extreme where two or more materials in nearly equal amounts are required to make a mixture of correct composition.

The almost infinite number of raw materials which are theoretically available are, however, reduced to a very few in practice under existing commercial conditions. The necessity for making the mixture as cheaply as possible rules out of consideration a large number of materials which would be considered available if chemical composition was the only thing

[a]Discussions of the material and method of Portland cement manufacture are contained in Bulletin No. 243, U. S. Geological Survey. A more detailed discussion of methods and costs of manufacture is contained in a volume by the present writer, entitled "Cements, Limes and Plasters," recently published by Wiley and Sons, of New York City.

to be taken into account. Some materials otherwise suitable are too scarce; some are too difficult to pulverize. In consequence, a comparatively few combinations of raw materials are actually used in practice.

In certain localities deposits of argillaceous (clayey) limestone or "cement rock" occur, in which the lime, silica, alumina, and iron oxide exist in so nearly the proper proportions that only a relatively small amount (say 10 per cent. or so) of other material is required in order to make a mixture of correct composition.

In the majority of plants, however, most or all of the necessary lime is furnished by one raw material, while the silica, alumina, and iron oxide are largely or entirely derived from another raw material. The raw material which furnishes the lime is limestone, chalk, or marl, while the silica, alumina, and iron oxide of the mixture are derived from clay, shale, or slate.

LIMESTONES.

Limestone is the most important ingredient, in one form or another, in a Portland cement mixture. Limestones of certain types are employed in the manufacture of hydraulic limes, natural cements, and slag cements. It will thus be seen that limestone is a very important constituent of all the cementing materials discussed in this bulletin. For this reason it has seemed desirable to discuss in the present section the origin, composition, varieties, and chemical and physical characters of limestone in general. This has been done in considerable detail. The present section will, therefore, serve as an introduction to the discussions of both the Portland and natural cements.

Origin of Limestones.

Limestones[a] have been formed largely by the accumulation at the sea bottom of the calcareous remains of such organisms as the foraminifera, corals, and mollusks. Many of the thick and extensive limestone deposits of the United States were probably marine deposits formed in this way. Some of these limestones still show the fossils of which they were formed, but in others all trace of organic origin has been destroyed by the fine grinding to which the shells and corals were subjected before their deposition at the sea bottom. It is probable also that a large part of the calcium carbonate of these limestones was a purely chemical deposit from solution, cementing the shell fragments together.

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[a]For a more detailed discussion of this subject the reader will do well to consult Chapter 8 of Prof. J. F. Kemp's Handbook of Rocks.

Other limestones, far less extensive, though important in the present connection, owe their origin to the indirect action of organisms. The "marls," so important to-day as Portland cement materials, fall in this class. As the deposits of this class are of limited extent, however, their method of origin may be dismissed here.

Deposition from solution by purely chemical means has undoubtedly given rise to numerous limestone deposits. When this deposition took place in caverns or in the open air it gave rise to onyx deposits and to the "travertine marls" of certain localities in Ohio and elsewhere. When it took place in isolated portions of the sea through the evaporation of the sea water it gave rise to the limestone beds which so frequently accompany deposits of salt and gypsum.

Varieties of Limestone.

A number of terms are in general use for the different varieties of limestone, based upon differences of origin, texture, composition, etc. The more important of these terms will be briefly defined.

The marbles are limestones which, through the action of heat and pressure, have become more or less distinctly crystalline, though the term marble is often extended to cover any limestone which will take a good polish. The term marl, as at present used in cement manufacture, is applied to a loosely cemented mass of lime carbonate formed in lake basins. Calcareous tufa and travertine are more or less compact limestones, deposited by spring or stream waters along their courses. Oölitic limestones, so called because of their resemblance to a mass of fish roe, are made up of small rounded grains of lime carbonate having a concentrically laminated structure. Chalk is a fine-grained limestone composed of finely comminuted shells, particularly those of the foraminifera. The presence of much silica gives rise to a siliceous or cherty limestone. If the silica present is in combination with alumina the resulting limestone will be clayey or argillaceous.

Chemical Composition of Limestone.

A theoretically pure limestone is merely a massive form of the mineral calcite. Such an ideal limestone would therefore consist entirely of calcium carbonate or carbonate of lime ($CaCO_3$), or 56 per cent. calcium oxide (CaO) plus 44 per cent. carbon dioxide or carbonic acid (CO_2). As might be expected, limestones as quarried differ more or less widely from this theoretical composition. These departures from ideal purity may take place

along either of two lines: (1) The presence of magnesia in place of part of the lime; (2) the presence of silica, iron, alumina, alkalies, or other impurities.

It seems advisable to discriminate between these two cases, even though a given sample of limestone may fall under both heads.

MAGNESIA IN LIMESTONE.

The theoretically pure limestones are, as above noted, composed entirely of calcium carbonate and correspond to the chemical formula $CaCO_3$. Setting aside for the moment the question of the presence or absence of such impurities as iron, alumina, silica, etc., it may be said that lime is rarely the only base in a limestone. During or after the formation of the limestone a certain percentage of magnesia is usually introduced in place of part of the lime, thus giving a more or less magnesian limestone. In such magnesian limestones part of the calcium carbonate is replaced by magnesium carbonate ($MgCO_3$), the general formula for magnesian limestone being therefore x $CaCO_3$, y $MgCO_3$. In this formula x may vary from 100 per cent. to zero, while y will vary inversely from zero to 100 per cent. Where the two carbonates are united in equal molecular proportions, the resultant rock is called dolomite. It has the formula $CaCO_3$, $MgCO_3$ and is composed of 54.35 per cent. calcium carbonate and 45.65 per cent. magnesium carbonate. If the calcium carbonate has been entirely replaced by magnesium carbonate, the resulting pure carbonate of magnesia is called magnesite, having the formula $MgCO_3$ and being composed of 47.6 per cent. magnesia (MgO) and 52.4 per cent. carbon dioxide (CO_2).

Rocks of the limestone series may therefore vary in composition from pure calcite limestone at one end of the series to pure magnesite at the other. The term limestone has, however, been restricted in general use to those rocks which have a composition between that of calcite and dolomite. All the more uncommon phases, carrying more than 45.65 per cent. magnesium, are usually described simply as impure magnesites.

The presence of much magnesia in finished Portland cement is considered undesirable, 3½ per cent. being the maximum permissible under most specifications. Therefore the limestone to be used in Portland cement manufacture should not carry over 5 or 6 per cent. of magnesium carbonate.

Though magnesia is often described as an "impurity" in limestone, this word, as can be seen from the preceding statements, hardly expresses the facts in the case. The magnesium carbonate present, whatever its amount, simply serves to replace an equivalent amount of calcium carbonate, and

the resulting rock, whether little or much magnesia is present, is still a pure carbonate rock. With the impurities to be discussed in later paragraphs, however, this is not the case. Silica, alumina, iron, sulphur, alkalies, etc., when present, are actual impurities, not merely chemical replacements of part of the calcium carbonate.

SILICA, IRON, AND OTHER IMPURITIES IN LIMESTONE.

A limestone consisting of pure calcium carbonate or of calcium carbonate with more or less magnesium carbonate may also contain a greater or lesser amount of distinct impurities. From the point of view of the cement manufacturer, the more important of these impurities are silica, alumina, iron, alkalies, and sulphur, all of which have a marked effect on the value of the limestone as a cement material.

The silica in limestone may occur either in combination with alumina as a clayey impurity, or not combined with alumina. As the effect on the value of the limestone would be very different in the two cases, they will be taken up separately.

Silica in limestone.—Silica, when present in a limestone containing no alumina, may occur in one of three forms, and the one in which it occurs is of great importance in connection with cement manufacture.

(1) In perhaps its commonest form silica is present in nodules, masses, or beds of flint or chert. Silica occurring in this form will not readily enter into combination with the lime of a cement mixture, and a cherty or flinty limestone is therefore almost useless in cement manufacture.

(2) In a few cases, as in the hydraulic limestone of Teil, France, a large amount of silica and very little alumina are present, notwithstanding which the silica readily combines with the lime on burning. It is probable that in such cases the silica is very finely divided or occurs as hydrated silica, which is possibly the result of chemical precipitation or of organic action. In the majority of cases, however, a highly siliceous limestone will not make a cement on burning unless it contains alumina in addition to the silica.

(3) In the crystalline limestones (marbles), and less commonly in uncrystalline limestones, silica may occur as a complex silicate in the form of shreds or crystals of mica, hornblende, or other silicate mineral. In this form silica is somewhat intractable in the kiln, and mica and other silicate minerals are therefore to be regarded as inert and useless impurities in a cement rock. These silicates will flux at a lower temperature than pure silica, and are thus not so troublesome as flint or chert. They are,

however, much less serviceable than if the same amount of silica were present in combination with alumina as a clay.

Silica with alumina in limestone.—Silica and alumina, combined in the form of clay, are common impurities in limestones and are of special interest to the cement manufacturer. The best-known example of such an argillaceous limestone is the cement rock of the Lehigh district of Pennsylvania. Silica and alumina when present in this combined form unite readily with the lime under the action of heat, and an argillaceous limestone, therefore, forms an excellent basis for a Portland cement mixture.

Iron in limestone.—Iron when present in a limestone occurs commonly as the oxide (Fe_2O_3) or sulphide (FeS_2); more rarely as iron carbonate or in complex silicates. Iron in the oxide, carbonate, or silicate forms is a useful flux, aiding in the combination of the lime and silica in the kiln. When present as a sulphide, in the form of the mineral pyrite, in quantities exceeding 2 or 3 per cent. it is to be avoided.

Physical Characters of Limestone.

In texture, hardness, and compactness the limestones vary from the loosely consolidated marls through the chalks to the hard, compact limestones and marbles. They differ in absorptive properties and density. The chalky limestones may have a specific gravity as low as 1.85, corresponding to a weight of 110 pounds per cubic foot, while the compact limestones, commonly used for building purposes, range in specific gravity between 2.3 and 2.9, corresponding approximately to a range in weight of from 140 to 185 pounds per cubic foot.

From the point of view of the Portland cement manufacturer these variations in physical properties are of economic interest chiefly in their bearing upon two points—the percentage of water carried by the limestone as quarried and the ease with which the rock may be crushed and pulverized. To some extent the two properties counterbalance each other; the softer the limestone the more absorbent is it likely to be.

Effect of Heat on Limestone.

On heating a nonmagnesian limestone to or above 300° C. its carbon dioxide will be driven off, leaving quicklime (calcium oxide, CaO). If a magnesian limestone be similarly treated, the product would be a mixture of calcium oxide and magnesium oxide (MgO). The rapidity and perfection of this decomposition can be increased by passing steam or air

through the burning mass. In practice this is accomplished either by the direct injection of air or steam or more simply by thoroughly wetting the limestone before putting it into the kiln.

If, however, the limestone contains an appreciable amount of silica, alumina, and iron, the effect of heat will not be of so simple a character. At temperatures of 800° C. and upward these clayey impurities will combine with the lime oxide, giving silicates, aluminates, and related salts of lime. In this manner a natural cement will be produced. An artificial mixture of a certain uniform composition, burned at a higher temperature, will give a Portland cement.

Argillaceous Limestone (Cement Rock).

An argillaceous limestone containing approximately 75 per cent. of lime carbonate and 20 per cent. of clayey materials (silica, alumina, and iron oxide) would, of course, be the ideal material for use in the manufacture of Portland cement, as such a rock would contain within itself in the proper proportions all the necessary ingredients. It would require the addition of no other material, but when burnt alone would give a good cement. This ideal cement material is, of course, never found, but certain argillaceous limestones approach it very closely in composition.

The most important deposit of these argillaceous limestones or "cement rocks" is that which is so extensively utilized in Portland cement manufacture in the Lehigh district of Pennsylvania and New Jersey.

Analyses of Lehigh district cement materials.

	Cement rock.				Limestone.	
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Silica (SiO_2)	10.02	9.52	14.52	16.10	3.02	1.98
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3)	6.26	4.72	6.52	2.20	1 .90	0.70
Lime carbonate ($CaCO_3$)	78.65	80.71	73.52	76.23	92.05	95.19
Magnesium carbonate ($MgCO_3$)	4.71	4.92	4.69	3.54	3.04	2.03

Certain Portland cement plants, particularly in the western part of the United States, use combinations of materials closely similar to those in the Lehigh district. Analyses of the materials used at several of these plants are given in the following table:

Analyses of "cement rock" and limestone from the western United States.

	Utah.		California.		Colorado.	
	Cement rock.	Limestone.	Cement rock.	Limestone.	Cement rock.	Limestone.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Silica (SiO_2)	21.2	6.8	20.06	7.12	14.20	....
Alumina (Al_2O_3)	8.0	3.0	10.07	2.36	5.21	....
Iron oxide (Fe_2O_3)	....	....	3.39	1.16	1.73	....
Lime carbonate ($CaCO_3$)	62.08	89.8	63.40	87.70	75.10	88.0
Magnesium carbonate ($MgCO_3$)	3.8	0.76	1.54	0.84	1.10	....

Soon after the American Portland cement industry had become fairly well established in the Lehigh district attempts were made in New York State to manufacture Portland cement from a mixture of pure limestone and clay. These attempts were not commercially successful, and although their failure was not due to any defects in the limestone used, a certain prejudice arose against the use of the hard limestones. In recent years, however, this has disappeared, and a very large proportion of the American output is now made from mixtures of limestone with clay or shale. The use of the hard limestone is doubtless due in great part to recent improvements in grinding machinery, for the purer limestones are usually much harder than argillaceous limestones like the Lehigh district "cement rock," and it was very difficult to pulverize them finely and cheaply with the crushing appliances in use when the Portland cement industry was first started in America.

A series of analyses of representative pure hard limestones, together with analyses of the clays or shales with which they are mixed, is given in the following table:

Analyses of pure hard limestones and clayey materials.

	Limestones.				Clays and shales.			
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Silica (SiO_2)	1.72	0.86	0.56	0.40	63.56	55.80	56.30	60.00
Alumina (Al_2O_3)	1.63	.63	1.23	.44	27.32	30.20	29.86	23.26
Iron oxide (Fe_2O_3)	6.59	1.03	.29					4.32
Lime carbonate ($CaCO_3$)	90.58	97.06	97.23	97.99	3.60	2.54	.....	1.70
Magnesium carbonate ($MgCO_3$)	......	......	.75	.42	2.60	......	.....	1.50

ALKALI WASTE.

A very large amount of waste material results from the manufacturing of caustic soda. This waste material is largely a precipitated form of calcium carbonate, and if sufficiently free from impurities furnishes a cheap source of lime for use in Portland cement manufacture.

The availability of alkali waste for this purpose depends largely on what process was used at the alkali plant. Leblanc-process waste, for example, carries a very large percentage of sulphides, which prevents its use as a Portland cement material. Waste resulting from the use of the ammonia process, on the other hand, is usually a very pure mass of lime, mostly in the form of carbonate, though a little lime hydrate is commonly present. As pyrite is not used in the ammonia process, the waste is usually low enough in sulphur to be used as a cement material. The waste may carry a low or a very high percentage of magnesia, according to the character of the limestone that has been used in the alkali plant. When a limestone low in magnesium carbonate has been used the resulting waste is a very satisfactory Portland cement material.

The following analyses are fairly representative of the waste obtained at alkali plants using the ammonia process:

Analyses of alkali waste.

	I.	II.	III.	IV.
	Per cent.	Per cent.	Per cent.	Per cent.
Silica (SiO_2)	0.60	1.75	1.98	0.98
Alumina (Al_2O_3)	3.04 (Alumina and iron oxide)	0.61	1.41	1.62 (Alumina and iron oxide)
Iron oxide (Fe_2O_3)			1.38	
Lime (CaO)	53.33	50.60	48.29	50.40
Magnesia (MgO)	0.48	5.35	1.51	4.97
Alkalies (Na_2O, K_2O)	0.20	0.64	0.64	0.50
Sulphur trioxide (SO_3)	n. d.	n. d.	1.16	n. d.
Sulphur (S)	n. d.	0.10	n. d.	0.06
Carbon dioxide (CO_2)	42.43	41.70 (Carbon dioxide and water)	39.60	n. d.
Water and organic matter	n. d.		3.80	n. d.

Of the analyses quoted in the preceding table, those in the first and third columns represent materials which are used in Portland cement manufacture in England and the United States. The alkali wastes whose analyses are given in the second and fourth columns are too high in magnesia to be advisable for such use.

BLAST-FURNACE SLAG.

True Portland cements, which must be sharply distinguished from the slag (or puzzolan) cements described on pages 29-32, can be made from a mixture of blast-furnace slag and limestone, which is finely powdered, and is then burned in kilns and the resulting clinker pulverized.

The slags from iron furnaces consist essentially of lime (CaO), silica (SiO_2), and alumina (Al_2O_3), though small percentages of iron oxide (FeO), magnesia (MgO), and sulphur (S) are commonly present. Slag may therefore be regarded as a very impure limestone or a very calcareous clay, from which the carbon dioxide has been driven off.

In the United States two plants manufacture true Portland cement from slag.

The slag used at a German Portland cement plant has the following range in composition:

Analysis of slag used in Portland cement manufacture.

	Per cent.
Silica (SiO_2)	30.0 to 35.0
Alumina (Al_2O_3)	10.0 to 14.0
Iron oxide (FeO)	.2 to 1.0
Lime (CaO)	46.0 to 49.0
Magnesium oxide (MgO)	.5 to 3.5
Sulphur trioxide (SO_3)	.2 to .6

CLAYS AND SHALES.

Clays are ultimately derived from the decay of older rocks, the finer particles being carried off by streams and deposited as beds of clay along channels, in lakes, or along parts of the seacoast or sea bottom. In chemical composition the clays are made up essentially of silica and alumina, though iron oxide is almost invariably present in more or less amount, while lime, magnesia, alkalies, and sulphur occur frequently, though usually only in small percentages.

Shales are clays which have become hardened by pressure. The so-called "fire-clays" of the "Coal Measures" are shales, as are many of the other "clays" of commerce.

For use as Portland cement materials clays or shales should be free from gravel and sand, as the silica present as pebbles or grit is practically inert in the kiln unless ground more finely than is economically practicable. In composition they should not carry less than 55 per cent of silica, and preferably from 60 to 70 per cent. The alumina and iron oxide together

should not amount to more than one-half the percentage of silica, and the composition will usually be better the nearer the ratio $Al_2O_3+Fe_2O_3=\frac{SiO_2}{3}$ is approached.

Nodules of lime carbonate, gypsum, or pyrite, if present in any quantity, are undesirable, though the lime carbonate is not absolutely injurious. Magnesia and alkalies should be low, preferably not above 3 per cent.

SLATE.

Slate is, so far as origin is concerned, merely a form of shale in which a fine, even, and parallel cleavage has been developed by pressure. In composition, therefore, it varies exactly as do the shales considered on previous pages, and so far as composition alone is concerned, slate would not be worthy of more attention, as a Portland cement material, than any other shale.

Commercial considerations in connection with the slate industry, however, make slate a very important possible source of cement material. Good roofing slate is relatively scarce and commands a good price when found. In the preparation of roofing slate for the market so much material is lost during sawing, splitting, etc., that only about 10 to 25 per cent. of the amount quarried is salable as slate. The remaining 75 to 90 per cent. is of no service to the slate miner. It is sent to the dump heap and is a continual source of trouble and expense. This very material, however, as can be seen from the analyses quoted below, is often admirable for use, in connection with limestone, in a Portland cement mixture. As it is a waste product it could be obtained very cheaply by the cement manufacturer.

Composition of American roofing slates.

	Maximum.	Average.	Minimum.
	Per cent.	Per cent.	Per cent.
Silica (SiO_2)	68.62	60.64	54.05
Alumina (Al_2O_3)	24.71	18.05	9.77
Iron oxide (FeO, Fe_2O_3)	10.66	6.87	2.18
Lime (CaO)	5.28	1.54	.00
Magnesia (MgO)	6.43	2.60	.12
Alkalies (K_2O, Na_2O)	8.68	4.74	1.93
Ferrous sulphide (FeS_2)	....	.38	....
Carbon dioxide (CO_2)	....	1.47	....
Water of combination	....	3.51	....
Moisture below 110° C.	....	.62	....

VALUE OF DEPOSITS OF CEMENT MATERIALS.

The determination of the possible value for Portland cement manufacture of a deposit of raw material is a complex problem, depending upon a number of distinct factors, the more important of which are as follows: (1) Chemical composition, (2) physical character, (3) amount available, (4) location with respect to transportation routes, (5) location with respect to fuel supplies, (6) location with respect to markets.

Ignorance of the respective importance of these factors frequently leads to an overestimate of the value of a deposit of raw material. Their effects may be briefly stated as follows:

(1) Chemical composition.—The raw material must be of correct chemical composition for use as a cement material. This implies that the material, if a limestone, must contain as small a percentage as possible of magnesium carbonate. Under present conditions, 5 or 6 per cent. is the maximum permissible. Free silica, in the form of chert, flint, or sand, must be absent, or present only in small quantity—say 1 per cent. or less. If the limestone is a clayey limestone, or "cement rock," the proportion between its silica and its alumina and iron should fall within the limits

$$\frac{SiO_2}{Al_2O_3 + Fe_2O_3} > 2 : \frac{SiO_2}{Al_2O_3 + Fe_2O_3} < 3\ 5.$$

A clay or shale should satisfy the above equation, and should be free from sand, gravel, etc. Alkalies and sulphates should, if present, not exceed 3 per cent.

(2) Physical character.—Economy in excavation and crushing requires that the raw materials should be as soft and as dry as possible.

(3) Amount available.—A Portland cement plant running on dry raw materials, such as a mixture of limestone and shale, will use approximately 20,000 tons of raw material a year per kiln. Of this about 15,000 tons are limestone and 5,000 tons shale. Assuming that the limestone weighs 160 pounds per cubic foot, which is a fair average weight, each kiln in the plant will require about 190,000 cubic feet of limestone a year. As the shale or clay may be assumed to contain considerable water, a cubic foot will probably contain not over 125 pounds of dry material, so that each kiln will also require about 80,000 cubic feet of shale or clay.

A cement plant is an expensive undertaking, and it would be folly to locate a plant with less than a twenty years' supply of raw material in sight. In order to justify the erection of a cement plant, *there must*

be in sight at least 3,800,000 cubic feet of limestone and 1,600,000 cubic feet of clay or shale for each kiln.

(4) Location with respect to transportation routes.—Portland cement is for its value a bulky product, and is therefore much influenced by transportation routes. To locate a plant on only one railroad, unless the railroad officials are financially connected with the cement plant, is simply to invite disaster. At least two transportation routes should be available, and it is best of all if one of these be a good water route.

(5) Location with respect to fuel supplies.—Every barrel (380 pounds) of Portland cement marketed implies that at least 200 to 300 pounds of coal have been used in the power plant and the kilns. In other words, each kiln in the plant will, with its corresponding crushing machinery, use up from 6,000 to 9,000 tons of coal a year. The item of fuel cost is therefore highly important, for in the average plant about 30 to 40 per cent. of the total cost of the cement will be chargeable to coal supplies.

(6) Location with respect to markets.—In order to achieve an established position in the trade, a new cement plant should have *(a)* a local market area, within which it may sell practically on a noncompetitive basis, and *(b)* easy access to a larger though competitive market area.

METHODS OF MANUFACTURE OF PORTLAND CEMENT.

If, as in this bulletin, the so-called "natural Portlands" are excluded, Portland cement may be regarded as an artificial product obtained by burning to semifusion an intimate mixture of pulverized materials containing lime, silica, and alumina in varying proportions within certain narrow limits, and by crushing finely the clinker resulting from this burning. If this restricted definition of Portland cement be accepted, four points may be regarded as being of cardinal importance: (1) The cement mixture must be of the proper chemical composition; (2) the materials must be carefully ground and intimately mixed before burning; (3) the mixture must be burned at the proper temperature; (4) after burning, the resulting clinker must be finely ground.

In the preparation of the mixture for the kiln the raw materials must be reduced to a very fine powder and intimately mixed. The raw materials are usually crushed more or less finely, then mixed, and then ground to powder. Two general methods of treatment, the dry and the wet, are in use at different plants. Unless the limy constituent of the mixture is a marl, already full of water, the dry method is almost invariably followed.

In this the materials are kept in as dry a condition as possible throughout the entire process of crushing and mixing, and if they originally contained a little moisture they are dried before being powdered and mixed. In the wet method, on the other hand, the materials are powdered and mixed while in a very fluid state, the mixture containing 60 per cent. or more of water.

With the exception of the marls and clays used in the wet method of manufacture, Portland cement materials are usually dried before the grinding is commenced. This is necessary because the raw materials, as they come from the quarry, pit, or mine, will almost invariably carry appreciable, though often very small, percentages of water, which greatly reduces the efficiency of most modern types of grinding mills and tends to clog the discharge screens.

The type of drier commonly used in cement plants is a cylinder, approximately 5 feet in diameter and about 40 feet in length, set at a slight inclination to the horizontal and rotating on bearings. The wet raw material is fed in at the upper end of the cylinder, and it moves gradually toward the lower end under the influence of gravity as the cylinder revolves. In many driers angle irons are bolted to the interior in such a way as to lift and drop the raw material alternately, thus exposing it more completely to the action of the heated gases and materially assisting in the drying process. The dried raw material falls from the lower end of the cylinder into an elevator boot and is then carried to the grinding mills.

The drying cylinder is heated either by a separate furnace or by waste gases from the cement kilns. In either case the products of combustion are introduced into the cylinder at its lower end, are drawn through it, and escape up a stack set at the upper end of the drier.

Part at least of the grinding is usually accomplished before the drying, but for convenience the subjects have been separated in the present paper. Usually the limestone is sent through a crusher at the quarry or mill, and occasionally the raw material is further reduced in a Williams mill, etc., before drying, but the principal part of the reduction always takes place after the material has been dried.

After the two raw materials have been separately dried they may be mixed immediately, or each may be further reduced separately before mixing. Automatic mixers, of which many types are on the market, give a mixture in proportions determined from analysis of the materials.

The further reduction of the mixture is usually carried on in two stages,

the material being ground to 30 mesh in a ball mill, comminuter, Griffin mill, etc., and finally reduced in a tube mill. At a few plants, however, single-stage reduction is practiced in Griffin or Huntington mills, while at the Edison plant at Stewartsville, N. J., the reduction is accomplished in a series of rolls.

The majority of plants use either the Griffin mill and tube mill or the ball and tube mills, and there is probably little difference in the cost of operating these two combinations. The ball mill has never been quite so successful as its companion, the tube mill, and has been replaced at several plants by the comminuter.

The cement mixture ready for burning will commonly contain from 74 to 77.5 per cent. of lime carbonate, or an equivalent proportion of lime oxide. Several analyses of actual cement mixtures are given in the table below. Analysis No. I, with its relatively high percentage of magnesia, is fairly typical of the Lehigh Valley practice. Analyses Nos. II. and III. show mixtures low in lime, while analysis No. IV. is probably the best proportioned of the four, especially in regard to the ratio between silica and alumina plus iron. The ratio, for ordinary purposes, should be about 2.5 or 3 to 1, as the cement sets quicker and has less ultimate strength as the percentage of alumina increases. If the alumina percentages be carried too high, moreover, the mixture will give a fusible, sticky clinker when burned, causing trouble in the kilns.

Analyses of cement mixtures.

	I.	II.	III.	IV.
	Per cent.	Per cent.	Per cent.	Per cent.
Silica (SiO_2)	12.62	13.46	13.85	14.77
Alumina (Al_2O_3) / Iron oxide (FeO)	6.00	?	7.20	4.35
Lime carbonate ($CaCO_3$)	75.46	73.66	73.93	76.84
Magnesia oxide (MgO_2)	2.65	?	?	1.74

After the cement mixture has been carefully prepared, as described in preceding pages, it must be burned with equal care. In the early days of the Portland cement industry a simple vertical kiln, much like that used for burning lime and natural cement, was used for burning the Portland cement mixture. These kilns, while fairly efficient so far as fuel consumption was concerned, were expensive in labor, and their daily output was small. In France and Germany they were soon supplanted by improved types, but still stationary and vertical, which gave very much lower fuel

consumption. In America, however, where labor is expensive, and fuel is comparatively cheap, an entirely different style of kiln has been evolved. This is the rotary kiln. With the exception of a very few of the older plants, which have retained vertical kilns, all American Portland cement plants are now equipped with rotary kilns.

The rotary kiln is a steel cylinder about 6 feet in diameter and, for dry materials, 60 to 110 feet long. For wet mixtures a kiln 80 to 100 feet long, or even longer, is frequently employed. This cylinder is set in a slightly inclined position, the inclination being approximately one-half inch to the foot. The kiln is lined, except near the upper end, with very resistant fire brick, to withstand both the high temperature to which its inner surface is subjected and the destructive action of the molten clinker.

The cement mixture is fed in at the upper end of the kiln, while fuel (which may be either powdered coal, oil, or gas) is injected at its lower end. The kiln, which rests upon geared bearings, is slowly revolved. This revolution, in connection with the inclination at which the clyinder is set, gradually carries the cement mixture to the lower end of the kiln. The intense heat generated by the burning fuel first drives off the water and carbon dioxide from the mixture and then causes the lime, silica, alumina, and iron to combine chemically to form the partially fused mass known as "cement clinker." This clinker drops out of the lower end of the kiln, is cooled to prevent injury to the grinding machinery, and is then sent to the grinding mills.

Rotary kilns are nominally rated at a production of 200 barrels a day per kiln. Even on dry and easily clinkered materials and with good coal, however, such an output is not commonly attained with a 60-foot kiln. Normally, a 60-foot kiln working on a dry mixture will produce from 160 to 180 barrels of cement each day of twenty-four hours. In doing this, if good coal is used, its fuel consumption will commonly be from 120 to 140 pounds of coal per barrel of cement, though it may range as high as 160 pounds, and, on the other hand, has fallen as low as 90 pounds. An output of 175 barrels a day, with a coal consumption of 130 pounds per barrel, may therefore be considered as representing the results of fairly good practice on dry materials with a 60-foot kiln. In dealing with a wet mixture, which may carry anywhere from 30 to 70 per cent. of water, the results are more variable, though always worse than with dry materials. In working a 60-foot kiln on a wet material, the daily output may range from 80 to 120 barrels, with a fuel consumption of from 150 to 250 pounds per barrel.

Using a longer kiln, partly drying the mixture and utilizing waste heat, will of course improve these figures materially.

The fuel most commonly used in modern rotary kiln practice is bituminous coal, pulverized very finely. Coal for this purpose should be high in volatile matter and as low in ash and sulphur as possible. Russell gives the following analyses of West Virginia and Pennsylvania coals used at present at various cement plants in Michigan:

Analyses of kiln coals.

	I.	II.	III.	IV.
	Per cent.	Per cent.	Per cent.	Per cent.
Fixed carbon	56.15	56.33	55.82	51.69
Volatile matter	35.41	35.26	39.37	39.52
Ash	6.36	7.06	3.81	6.13
Moisture	6.08	1.35	1.00	1.40
Sulphur	1.30	1.34	.42	1.48

The coal as usually bought is either "slack" or "run of mine." In the latter case it is necessary to crush the lumps before proceeding further with the preparation of the coal, but with slack this preliminary crushing is not necessary, and the material can go directly to the drier.

Coal as bought may carry as high as 15 per cent. of water in winter or in wet seasons. Usually it will run from 3 to 8 per cent. To obtain good results from the crushing machinery this water must be driven off. For coal drying, as for the drying of raw materials, the rotary drier seems best adapted to American conditions. It should be said, however, that in drying coal it is usually considered inadvisable to allow the products of combustion to pass through the cylinder in which the coal is being dried. This restriction serves to decrease slightly the possible economy of the drier, but an evaporation of 6 to 8 pounds of water per pound of fuel coal can still be counted on with any good drier. The fuel cost of drying coal containing 8 per cent. of moisture, allowing $2 per ton for the coal used as fuel, will therefore be about 3 to 4 cents per ton of dried product.

Though apparently brittle enough when in large lumps, coal is a difficult material to pulverize finely. For cement-kiln use, the fineness of reduction is extremely variable. The finer the coal is pulverized the better results will be obtained from it in the kiln, and the poorer the quality of the coal the finer it must be pulverized. The fineness attained in practice may therefore vary from 85 per cent., through a 100-mesh sieve, to 95 per cent. or more through the same. At one plant a very poor but cheap coal is pul-

verized to pass 98 per cent. through a 100-mesh sieve, and in consequence gives very good results in the kiln.

Coal pulverizing is usually carried on in two stages, the material being first crushed to 20 to 30 mesh in a Williams mill or ball mill, and finally reduced in a tube mill. At many plants, however, the entire reduction takes place in one stage, Griffin or Huntington mills being used.

The power and machinery required for pulverizing the clinker at a Portland cement plant using the dry process of manufacture are not much more than those needed for pulverizing the raw materials. This may seem at first sight improbable, for Portland cement clinker is much harder to grind than any possible combination of raw materials; but it must be remembered that for every barrel of cement produced about 600 pounds of raw material must be pulverized, while only a scant 400 pounds of clinker will be treated, and that the large crushers required for some raw materials can be dispensed with in crushing clinker. With this exception, the machinery for treating the raw material and that for treating the clinker of a dry-process Portland cement plant are usually almost duplicates.

The difficulty, and in consequence the expense, of grinding clinker will depend in large part on the chemical composition of the clinker and on the temperature at which it has been burned. The difficulty of grinding, for example, increases with the percentage of lime carried by the clinker, and a clinker containing 64 per cent. of lime will be very noticeably more resistant to pulverizing than one containing 62 per cent. of lime. So far as regards burning, it may be said in general that the more thoroughly burned the clinker the more difficult it will be to grind, assuming that its chemical composition remains the same.

The tendency among engineers at present is to demand more finely ground cement. While this demand is doubtless justified by the results of comparative tests of finely and coarsely ground cements, it must be borne in mind that any increase in fineness of grinding means a decrease in the product per hour of the grinding mills employed, and a consequent increase in the cost of cement. At some point in the process, therefore, the gain in strength due to fineness of grinding will be counterbalanced by the increased cost of manufacturing the more finely ground product.

The increase in the required fineness has been gradual but steady during recent years. Most specifications now require at least 90 per cent. to pass a 100-mesh sieve, a number require 92 per cent., while a few important specifications require 95 per cent.

ADDITION OF GYPSUM.

The cement produced by the rotary kiln is invariably naturally so quick-setting as to require the addition of sulphate of lime. This substance, when added in quantities up to 2½ or 3 per cent., retards the rate of set of the cement proportionately, and appears to exert no injurious influence on the strength of the cement. In amounts over 3 per cent., however, its retarding influence seems to become at least doubtful, while a decided weakening of the cement is noticeable.

Sulphate of lime may be added in one of two forms, either as crude gypsum or as burned plaster. Crude gypsum is a natural hydrous lime sulphate, containing about 80 per cent. of lime sulphate and 20 per cent. of water. When gypsum is calcined at a temperature not exceeding 400° F., most of its contained water is driven off. The "plaster" remaining carries about 93 per cent. of lime sulphate, with only 7 per cent. of water.

In Portland cement manufacture either gypsum or burned plaster may be used to retard the set of the cement, but gypsum is universally employed in the United States. This is merely a question of cost. It is true that to secure the same amount of retardation of set it will be necessary to add a little more gypsum than burned plaster, but gypsum is much cheaper than burned plaster.

The addition of the gypsum to the clinker is usually made before it has passed into the ball mill, comminuter, or whatever mill is in use for preliminary grinding. Adding it at this point insures much more thorough mixing and pulverizing than if the mixture were made later in the process. At some of the few plants which use plaster instead of gypsum the finely ground plaster is not added until the clinker has received its final grinding and is ready for storage or packing.

NATURAL CEMENTS.

The term "natural cements" is here used to include all cements produced by burning a natural limestone rock without previous grinding or mixing.

Natural cements are produced by burning a natural clayey limestone, containing 15 to 40 per cent. of silica, alumina, and iron oxide, without preliminary mixing and grinding. The burning takes place at a temperature that is usually little, if any, above that of an ordinary lime-kiln. During the burning the carbon dioxide of the limestone is almost entirely driven off, and the lime combines with the silica, alumina, and iron oxide, forming a mass containing silicates, aluminates, and ferrites of

lime. In case the original limestones contained any magnesium carbonate the burned rock will contain a corresponding amount of magnesia and magnesian compounds.

The burned mass will not slake if water be poured on it. It is necessary, therefore, to grind it rather fine; after it is ground, if the resulting powder (natural cement) be mixed with water, it will harden rapidly. This hardening or setting will take place either in air or under water.

RELATIONS OF NATURAL CEMENTS TO OTHER CEMENTS.

Natural cements differ from ordinary limes in two very noticeable ways: (1) The burned mass does not slake when water is poured on it. (2) Natural cement powder has hydraulic properties; i. e., if properly prepared it will set under water.

Natural cements differ from Portland cements in the following important particulars: (1) Natural cements are made by burning masses of natural rock, not by burning carefully prepared and finely ground artificial mixtures. (2) Natural cements, after burning and grinding, are usually yellow to brown and light in weight, their specific gravity being about 2.7 to 2.9; Portland cement is commonly blue to gray in color and heavier, its specific gravity ranging from 3.0 to 3.2. (3) Natural cements are always burned at a lower temperature than Portland, and commonly at a much lower temperature, the mass of rock in the kiln never being heated high enough to even approach the fusing or clinkering point. (4) Natural cements set more rapidly than Portland cement, but do not attain so high ultimate strength. (5) Various brands of natural cements will show very great differences in composition, while Portland cement is a definite product whose percentages of lime, silica, alumina, and iron oxide vary only between narrow limits.

RAW MATERIAL (NATURAL-CEMENT ROCK).

The material used in the manufacture of natural cement is invariably a clayey limestone, carrying from 13 to 35 per cent. of clayey material, of which 10 to 22 per cent. or so is silica, while alumina and iron oxide together may vary from 4 to 16 per cent. These clayey materials give the resulting cement its hydraulic properties. Stress is often carelessly or ignorantly laid on the fact that many of the best known natural cements carry large percentages of magnesia, but magnesia (in natural cements at least) may be regarded as being almost exactly interchangeable with lime, so far as the hydraulic properties of the product are concerned. The

presence of magnesium carbonate in a natural cement rock is then merely incidental, while the silica, alumina, and iron oxide are essential. The 30 per cent. or so of magnesium carbonate which occurs in the cement rock of the Rosendale district, New York, could be replaced by an equal amount of lime carbonate and the burnt stone would still give a hydraulic product. If, however, the clayey portion (silica, alumina, and iron oxide) of the Rosendale rock could be removed, leaving only the magnesium and lime carbonates, the burnt rock would lose all of its hydraulic properties and would yield simply a magnesian lime.

This point has been emphasized because many writers on the subject have either explicitly stated or implied that it is the magnesian carbonate of the Rosendale, Akron, Louisville, Utica, and Milwaukee rocks that causes them to yield a natural cement on burning.

Since within very wide limits of composition any clayey limestone will give a natural cement on burning, it can readily be seen that satisfactory natural cement materials must be widely distributed and of common occurrence. Hardly a state is entirely without limestones sufficiently clayey to be available for natural cement manufacture. The sudden rise of the American Portland cement industry, however, has acted to prevent any great expansion of the natural cement industry. It would be difficult to place a new natural cement on the market in the face of competition from both Portland cement and from the older and well-established brands of natural cement. Such new natural cement plants as have been started within recent years have mostly been located in old natural cement districts, where the accumulated reputation of the district would help to introduce the new brand. The only exceptions to this rule, indeed, were the Pembina plant in North Dakota, the Rossville plant in Georgia, and a plant in the state of Washington. Of these, the Pembina plant was established with the intention of making Portland cement, but the raw materials soon proved to be unsuitable and the plant was converted. The plant in Washington is located in an area where any kind of cement is readily salable. The Rossville plant was built by an Akron, N. Y., cement manufacturer to utilize a peculiarly satisfactory natural cement rock.

METHODS OF MANUFACTURE.

The manufacturing methods at a natural cement plant are of the simplest kind, including merely the burning of the cement rock and the pulverizing of the product.

The burning is carried on in vertical kilns, closely resembling lime

kilns in shape, size, etc. The limestone and fuel are usually fed into the kiln in alternate layers, though at a few plants more advanced types of kilns are in use. The burned product is crushed and then reduced to powder, commonly in buhrstone mills. Recently advances have been made in crushing practice, and several plants now reduce their product in tube mills.

PUZZOLAN CEMENTS.

Puzzolanic materials include all those natural or artificial substances that are capable of forming hydraulic cements on being simply mixed with lime, without the use of heat. Many materials possess this property, but relatively few have ever attained sufficient commercial importance to be discussed here. In composition the puzzolanic materials are largely made up of silica and alumina, usually with more or less iron oxide; some, as the slags used in cement manufacture, carry also notable percentages of lime. As might be inferred from this composition, most of the puzzolanic materials possess hydraulicity to a greater or less degree, but the addition of lime usually greatly increases their hydraulic power.

Slag (puzzolan) cement is made by intimately mixing granulated blast-furnace slag of proper composition with slaked lime, and reducing this mixture to a fine powder. This product, though usually called a Portland cement by the manufacturers, is different from a true Portland in both its rational and ultimate compositions and in its processes of manufacture. Further than this and more important from the purchasers' standpoint, a cement of this class has certain qualities which prevent its being used as an exact substitute for Portland cement, though it is a good enough material for certain uses.

COMPOSITION OF THE SLAG.

The slag used in cement manufacture must be basic blast-furnace slag. Tetmajer, the first investigator of slag cements, announced as the results of his experiments (*a*) that the hydraulic properties of the slag increased with the proportion of lime contained in it, and that slags in which the ratio $\frac{CaO}{SiO_2}$ was so low as to approach unity were valueless for cement manufacture; (*b*) that, so far as the alumina content of the slag was concerned, the best results were obtained when the ratio $\frac{Al_2O_3}{SiO_2}$ gave a value of 0.45 to 0.50; and (*c*) that with any large increase of alumina

above the amount indicated by this value of the alumina-silica ratio the tendency of the cement to crack (when used in air) was increased.

Prost, at a later date, investigated the subject, using for experiment several commercial slags and also a series prepared from pure CaO, SiO_2, and Al_2O_3. He decided that the hydraulic properties (both as regards rapidity of set and ultimate strength) of the slag increased as the proportions of lime and alumina increased, and failed to find any indication that a high alumina content causes disintegration. His best results were obtained from slags having the compositions respectively of $2SiO_2$, Al_2O_3, 3CaO and $2SiO_2$, Al_2O_3, 4CaO.

Mahon in 1893 made a series of experiments to determine the value (for cement manufacture) of a large series of the slags produced by the furnaces of the Maryland Steel Company, and found that the slags giving the best results were two, having respectively the following compositions:

(1) SiO_2, 30 per cent.; Al_2O_3, 17 per cent.; CaO, 47.5 per cent.; S, 2.38 per cent.; and (2) SiO_2, 25.3 per cent.; Al_2O_3, 20.1 per cent.; CaO, 48 per cent.; MgO, 3.28 per cent.; S, 2.63 per cent.

The ratios of $\frac{CaO}{SiO_2}$ and $\frac{Al_2O_3}{SiO_2}$, calculated for these slags, are—

(1) $\frac{CaO}{SiO_2}=1.58$; $\frac{Al_2O_3}{SiO_2}=0.57$; and (2) $\frac{CaO}{SiO_2}=1.9$; $\frac{Al_2O_3}{SiO_2}=0.79$.

At the close of the experiments Mahon recommended that slags be used even slightly higher in alumina than those above quoted.

The specifications under which slag from the furnaces is accepted by the cement department of the Illinois Steel Company are as follows:

(1) Slag must analyze within the following limits:

$SiO_2+Al_2O_3$, not over 49 per cent.; Al_2O_3, from 13 to 16 per cent.; MgO, under 4 per cent.

(2) Slag must be made in a hot furnace and must be of a light-gray color.

(3) Slag must be thoroughly disintegrated by the action of a large stream of cold water directed against it with considerable force. This contact should be made as near the furnace as is possible.

A series of over 300 analyses of slags used by this company in their slag (puzzolanic) cement show the following range in composition:

SiO_2, 29.60 to 35.60 per cent.; Al_2O_3 and Fe_2O_3, 12.80 to 16.80 per cent.; CaO, 47.99 to 50.48 per cent.; MgO, 2.09 to 2.81 per cent.

The requirements of the Birmingham Cement Company as to the chemical composition of the slags used for cement are as follows: The lime content shall not be less than 47.9 per cent.; the silica and lime

together shall approximately amount to 81 per cent.; and the alumina and iron oxide together shall equal from 12 to 15 per cent.

Analyses of a number of slags used in cement manufacture are shown in the table below. The analyses of foreign slags are quoted from various reliable authorities and the five analyses of the Illinois Steel Company slags have been selected from a large series to show the extreme ranges of the different elements. The ratios $\frac{CaO}{SiO_2}$ and $\frac{Al_2O_3}{SiO_2}$ have been calculated for each slag and are shown in this table.

From these data it can be seen that the ratio of alumina to silica is carried very high at Choindez; and is rather low at Chicago, relatively to most of the European plants. It must be remembered, however, that one reason for carrying a high alumina-silica ratio does not apply at Chicago, as there rapidity of set is gained by the use of the Whiting process. Taking these two plants as representative of the best European and American practice, the average of the analyses given shows the ratios actually used to be: Choindez, Switzerland, $\frac{CaO}{SiO_2}=1.71$, $\frac{Al_2O_3}{SiO_2}=0.90$, and Chicago, Ill., $\frac{CaO}{SiO_2}=1.49$, $\frac{Al_2O_3}{SiO_2}=0.44$.

These results may be compared with the theoretical ratios advised by Tetmajer, Prost, and Mahon.

Analyses of slags used in slag cements.

	Silica (SiO_2).	Alumina (Al_2O_3).	Iron oxides (FeO, Fe_2O_3).	Lime (CaO).	Magnesia (MgO).	Lime sulphide (CaS).	Lime sulphate ($CaSO_4$).	Sulphur (S).	Sulphur trioxide (SO_3).	Ratio, $\frac{CaO}{SiO_2}$.	Ratio, $\frac{Al_2O_3}{SiO_2}$.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.		
1.	30.00	28.00	0.75	32.75	5.25	1.90	....	.....	......	1.09	0.93
2.	31.50	18.56	....	42.22	3.18	......	....	0.45	2.21	1.34	.59
3.	32.90	13.25	.46	47.30	1.37	3.42	....	.....	......	1.44	.41
4.	31.50	16.62	.62	46.10	......	......	....	.....	......	1.46	.52
5.	26.88	24.12	.44	45.11	1.09	1.86	....	.....	......	1.68	.89
6.	27.33	23.81	.63	45.83	.92	1.34	0.17	.....	.....	1.67	.87
7.	26.24	24.74	.49	46.83	.88	.59	.32	.....	......	1.78	.93
8.	32.20	15.50	....	48.14	2.27	......	....	.....	......	1.49	.48
9.	33.10	12.60	....	49.98	2.45	......	....	.....	......	1.51	.38
10.	31.80	14.80	....	49.74	2.29	......	....	.....	......	1.56	.46
11.	34.30	14.76	....	48.11	2.66	......	....	.....	......	1.40	.43

1, 2. Middlesborough, England.
3. Bilbao, Spain.
4. Saulnes, France.
5, 6, 7. Choindez, Switzerland.
8, 9, 10, 11. Chicago, Ill.

The erection of a slag cement plant in connection with any given furnace is not justified unless a sufficient amount of the slags usually produced will fall within the slag-cement requirements, which have been outlined above in the section on chemical composition of the slag (?). In a large plant it will usually be easy to secure a constant supply of slag of proper composition without interfering with the proper running of the furnaces. In a small plant, however, or in one running on a number of different ores, such a supply may be difficult to obtain. These points, of course, should be settled in advance of the erection of the cement plant.

In the case of any given furnace running on ores and fluxes which are fairly steady in composition and proportions, the selection of the slag used for cement making may often be largely based on its color, checked by determinations of lime. The dark-colored slags are generally richest in lime, except when the depth of color is due to the presence of iron; the lighter-colored slags are usually higher in silica and alumina.

GENERAL GEOLOGY AND TOPOGRAPHY OF WESTERN VIRGINIA

Geographically, the state of Virginia may be divided into three parts; first an eastern division commonly known as the coastal plain, second, a large, plateau-like central area bounded upon the west by the Blue Ridge mountains, and third, a western portion embracing the Valley of Virginia and the various valleys and ridges westward to the state line. The boundaries of these three parts, or physiographic provinces, are shown on the accompanying sketch map. Geologically considered, the same three divisions may be maintained. The eastern portion of the state is underlain by Cenozoic and more recent rocks, the central area, or Piedmont plateau, exposes the very ancient crystalline rocks with a few comparatively small basins containing Mesozoic deposits, while the western part shows all the main divisions of Paleozoic strata. Both the eastern and western divisions furnish considerable raw material suitable for the manufacture of cement, but the nature of this material is so different in the two areas that it has been deemed best to consider them separately. The present report, therefore, deals only with the limestones and shales of the larger western area, while the consideration of the limestones, shales, clays and marls of the other divisions is reserved for a future publication.

Three well marked topographic belts may be recognized in western or Appalachian Virginia. These are, in order from east to west, the Blue Ridge, the Great Valley, or Valley of Virginia, and the Alleghany mountains.

The Blue Ridge is composed largely of pre-Cambrian rocks, but sandstones and shales of Lower Cambrian age outcrop along the western slope. This arrangement of the rock holds throughout Virginia as well as the states to the north and south. The Blue Ridge, therefore, forms a natural dividing line between the Paleozoic sandstones, limestones, and shales to the west and the pre-Paleozoic and other rocks to the east.

The physiography of the Valley of Virginia has been described by Dr. Thomas L. Watson in his "Lead and Zinc Deposits of Virginia."[a] A portion of Doctor Watson's description is repeated below:

[a]Geol. series, Bull. No. 1, Geol. Surv. Virginia, 1905.

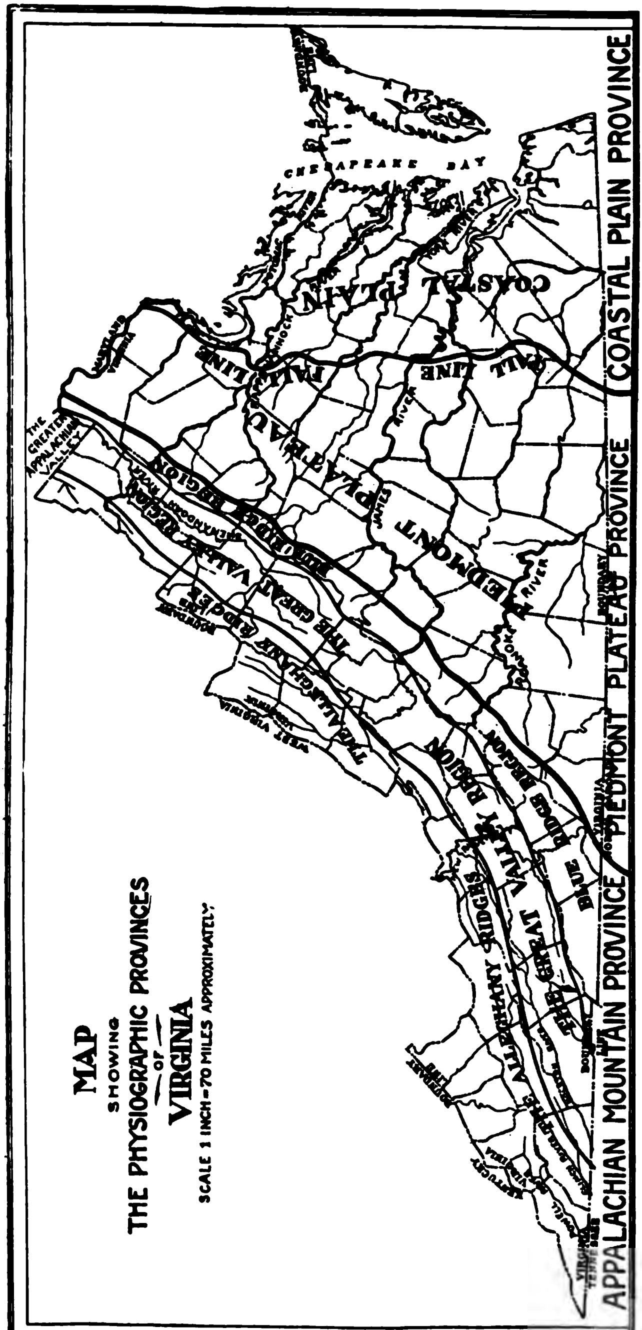

Fig. 1.—Sketch map of Virginia showing physiographic provinces.

"The Appalachian Valley forms a long, narrow belt, whose general surface is depressed below that of the highlands on either side. It has a general northeast-southwest trend which conforms to the structural axes of the Appalachians. It is not a simple valley, but is a structural belt of marked irregularities, composed of successively smaller valleys separated by moderately high and fairly steep-sided ridges, which in many places present a relief of as much as a thousand feet and more. When studied in detail the general surface of the Valley is very different in different localities. In places the surface relief is not great, while over much of the belt the surface is rougher and in places so rough and broken that it is difficult to cross.

"The Valley shows a gradual increase in altitude of 2,000 feet at the Tennessee-Virginia line to 2,500 or 2,700 feet at its highest point on the divide between the New and Tennessee rivers. From this point it descends to 2,200 feet in the valley of New river to 1,000 or 1,500 feet in the James river valley.

"The Valley occupies a belt of intensely folded strata, which in many cases have been broken across and thrust for considerable distances out of their original position. It owes its characteristic features directly to the structure and character of the rocks. The valleys are usually deep and narrow and have been determined by the soft and weaker underlying shales and limestones. The form and altitude of the ridges are determined by the character of the rock and the position of the strata composing them. In other words the lines of drainage over the region are well adjusted to the rock structure. The streams have established their courses largely on the soft rocks, shale and limestone, which form the valleys, and they have avoided the harder and more resistant rocks, such as sandstone and quartzite, which are ridge-forming.

"The Appalachian Valley has been a land area since early Mesozoic time. During this time the region has not remained stationary with respect to sea level, but field evidence indicates several periods of uplift followed by intervals of quiescence. Each period of elevation caused increased activity to the streams and to the atmospheric agents in general, which resulted in the lowering or down-wearing of the surface. The periods of quiescence which followed each uplift were sufficiently long to enable the streams to establish a system of base-levels over the entire region; and the region was also stationary for a time sufficient to admit of the inter-stream areas being lowered to an approximately uniform level. The harder and more resistant rocks, such as sandstone and quartzite, were never

entirely reduced, but they mark partially unreduced residuals which stand in relief above the general level of the erosion plane.

"Accordingly, evidence favoring several periods of base-leveling and planation is recorded over the Virginia area. The oldest and most extensive peneplain was probably formed in Cretaceous time. The surface of the Cretaceous peneplain is believed to be marked by portions of the crestline of Cove, Little Walker, Big Walker, Rich, and East River mountains over the central and western parts of the southwest Virginia Valley region. The period of quiescence which resulted in the formation of the Cretaceous peneplain was interrupted by a gradual uplift which raised the surface much above its former position. This elevation was not equal over all parts of the region and the plain was warped by differential uplift. Following this period of uplift were periods of quiescence of shorter duration, which resulted in the formation of other peneplains during the Eocene and Miocene periods. More recently the region has again been elevated and the major streams have cut down their valleys nearly or quite to the base-level."

The "Valley" limestone, or, as it was renamed, the Shenandoah limestone, occupies the greater part of the floor of the Great Valley. To the rich soils resulting from the disintegration of this limestone is due the agricultural wealth of this part of the state.

In comparison with the Valley portion of Virginia, the areas occupied by the Alleghany mountains are small, consisting first of a strip near the center of the western border in the vicinity of Covington, and second, of a somewhat larger portion in the southwestern part of the state. The physiography of this area well illustrates the dependence of topography upon the structure and nature of the strata. Folding and faulting of the Paleozoic rocks and subsequent erosion have here given rise to parallel ridges with a common northeast and southwest trend. These ridges mark the repeated outcrop of certain strata and owe their existence to the resistant character of the rock. The summits of the ridges throughout this region are approximately of the same height and indicate the old base-level surface.

The geological formations of the region west of the Blue Ridge in Virginia were described by Prof. Wm. B. Rogers under fourteen (14) groups of strata which were designated by numbers, beginning with the oldest. Prof. H. D. Rogers divided the Paleozoic rocks in Pennsylvania into fifteen (15) sets of formations "extending from the deposits which witnessed the very dawn of life upon the globe to those which saw the

close of the long American Paleozoic day." The names assigned to these formations were those of the various parts of the day instead of geographic terms. Thus the extremes of his classification were the Primal, signifying the Dawn, and corresponding to the lower Cambrian quartzites, and the Seral or Nightfall, equivalent to the "Coal Measures." In the literature bearing upon Virginia, both sets of names have been employed. The following table is therefore introduced to show the relationship between these designations and the terms now in use. Comparison of this table with those given on other pages will show more exactly the equivalence of the present geographic formation names.

Correlation table of geologic formations of western Virginia.

Era.	Period.		Virginia and Pennsylvania Report Numbers.	First Pennsylvania Report Names.
Paleozoic	Pennsylvanian		XIV, XIII, XII	Seral.
	Mississippian	Upper	XI	Umbral
		Lower	X	Vespertine.
	Devonian	Upper	IX, VIII	Ponent. Vergent, Cadent.
		Middle	VII	Post-Meridian, Meridian.
		Lower	VI	Pre-Meridian.
	Silurian	Upper	V	Scalent.
		Middle	V	Surgent.
		Lower	IV	Levant.
	Ordovician	Upper	III	Matinal.
		Middle	III	Matinal.
		Lower	II	Auroral.
	Cambrian	Upper	II	Auroral.
		Middle	II	Auroral.
		Lower	I	Primal.

Notes Upon Limestones.

A description of the various kinds of limestones has been given on a former page, but the following notes are introduced here to explain certain terms employed in the succeeding pages. Because of their variation in both physical and chemical composition, various subordinate names are applied to limestones. The magnesian content varies and thus gives rise to several distinguishing terms. For example, if the amount of magnesium carbonate is 5 per cent. or less, the rock can be spoken of as a rather pure,

or more or less pure, limestone, when the remaining 95 or more per cent. is calcium carbonate. Magnesian or dolomitic limestone may contain 5 to 45 per cent. of magnesium carbonate, but above the latter percentage the rock becomes a dolomite.

According to their uses, limestones may be classed as rocks suitable (1) for the burning of lime, and (2) for the making of cement. The cement rocks contain a varying amount of clayey material as well as magnesium and calcium carbonates, and these are distinguished as (1) slightly argillaceous, (2) argillaceous, or (3) argillaceous magnesian limestone.

The color of limestones depends mainly upon impurities. Pure calcite is white, so an absolutely pure crystalline limestone would also be white. In western Virginia this condition is closely approached by some of the Holston marbles and by certain beds of the Murat limestone. Gray to black limestones usually contain a very small percentage of organic matter, while red to yellow shades are produced by iron oxide. In the following pages, dove limestones are frequently mentioned. These refer to strata that are in color of a warm gray or pinkish or purple tone, and of a texture so fine-grained and smooth that the individual granules are imperceptible. These dove limestones almost invariably show a high lime composition upon analysis.

Argillaceous limestones, or those most valuable as cement materials directly, are of a dark or black color, and usually give forth a clayey odor when breathed upon.

Limestones occur in all of the greater geological divisions of western Virginia. However, the strata of greatest purity, as well as those suitable for cement purposes, are restricted to certain formations, which it therefore becomes necessary to accurately locate.

Folding and Faulting.

If the simple horizontal arrangement of the rocks of western Virginia existing when deposited still obtained, their study and mapping would be less difficult, but the strata have subsequently been much complicated by folding and faulting. In consequence of this deformation, it is often difficult to trace a stratum or succession of strata, especially when the outcrops are few and obscure. The present attitude of the rocks indicates that in general these originally horizontal strata have been bent into great folds whose axes extend as a rule in a northeast-southwest direction. Since this folding occurred, sufficient time has elapsed for the rocks to be greatly eroded. The upfolds or anticlines offer the greatest opportunity for

Fig. 1.—View of an overthrust fault at Ben Hur, Va. The Ordovician (Chickamauga, division 2) limestone is thrust upon the Devonian (Chattanooga) shale. The contact of the two formations is marked by crumpling and slickensiding of the strata.

Fig. 2.—A fault of small magnitude in division 2 of the Chickamauga limestone near Ben Hur, Here the break in the continuity of the strata is only ten or fifteen feet.

FAULTED STRATA OF WESTERN VIRGINIA.

erosion, and, as a result, many feet of strata have been worn away from their arches. On account of this erosion, the older strata, which were formerly deeply buried, are now exposed to view along the axes of the anticlines, while the younger strata dip or slant away on each side. The rock formations are therefore exposed in long, narrow belts, the width of the belts depending upon the thickness of the formation and the angle of dip. In the downfolds of the strata, or synclines, these relations are reversed, rocks of younger age occupying the central portion of the fold with the older strata dipping toward them.

Such an arrangement of the rocks is shown in some of the general structure sections across the Great Valley from the Blue Ridge to the Alleghanies. These structure sections present the view of the rocks that would be revealed by a ditch cut across their edges, and are especially valuable in illustrating the folding and faulting to which a region has been subjected.

If this arrangement of the rocks prevailed, it would be a comparatively easy matter to locate the various belts of rock, but such simple folding is the exception. The movements to which the earth's crust has been subjected have given rise to fracturing as well as folding, fracturing occurring when the strata were unable to accommodate themselves to these compressive forces by mere bending. Such fractures or faults are of common occurrence in Virginia, a series of older rocks often being found thrust upon or completely covering strata of younger age. To illustrate the various methods of faulting commonly found in the Appalachian district of Virginia, and to show the geologic features of particular areas, structure sections are introduced in the following pages. Faulting in this region, as well as in the Appalachian mountains generally, was first investigated by Profs. W. B. and H. D. Rogers during the progress of their geological surveys of Virginia and Pennsylvania, and their results formed the basis for all subsequent work along this line.

Two classes of faults are distinguished: (1) normal or gravity faults in which the fractured strata, on account of gravity and the tension to which they are subjected, arrange themselves into such positions that their beds are not continuous; (2) reversed or overthrust faults in which, by compression, the broken strata are thrust past and over each other. Faults of this latter class are most numerous and characteristic in highly folded regions, and abundant in western Virginia. On the other hand, normal faults are seldom found in such a region, so that this class of faults is the exception in the area under discussion. Although normal faults no doubt

existed in Appalachian Virginia, the compression to which the region has been subjected from time to time has changed most of them to thrust faults.

The detection of faults in the strata is by no means an easy matter. Small faults in well exposed strata are indicated by the discontinuity of the rocks as in figure 2, of the accompanying plate. In faults of great magnitude, however, the strata often appear conformable and a knowledge of the detailed stratigraphy of the region is necessary to detect the break. Thus, in figure 1 of plate I, the Lower Ordovician limestones are thrust upon Middle Devonian shale, several thousand feet of strata being cut out by this overthrust.

PORTLAND CEMENT MATERIALS OF WESTERN VIRGINIA.

In the Appalachian mountain province of Virginia, the prominent sources of cement material, listed in geologic order, are as follows.

5. Mississippian (Greenbrier) limestone and (Pennington) shale.
4. Devonian (Helderbergian) limestone and black shale.
3. Silurian (Cayugan) limestone and shale.
2. Ordovician (Trenton, etc.) limestones and shales.
1. Cambrian—impure limestone and shale.

Of these, the limestones and shales of Ordovician age are most promising on account of their abundance and usually favorable chemical composition. For these reasons the greater part of the field work has been concentrated upon these strata and the present report is therefore largely occupied with their discussion. The Cambrian limestones form an especially difficult subject of study, and much more field work is necessary before they can be accurately correlated and mapped. The Cayugan and Helderbergian limestone (Lewistown) is now used in Portland cement manufacture at Craigsville, Augusta county, while the Mississippian limestone will probably become an important source of cement material in southwestern Virginia. The Ordovician shales and limestones have a wider distribution and are usually more accessible than any other of the cement rock horizons of the state. In general the entire Valley of Virginia is underlain by Cambrian and Ordovician limestones, while the shales usually outcrop along the base of the mountains bounding it. In a similar manner many of the valleys west of the Great Valley show these limestones and shales, higher formations occurring on the separating ridges.

A study of the Cambrian and Ordovician rocks of Virginia has shown

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that the state may be divided into three more or less well defined areas, in each of which the geologic sequence differs to some extent. Considering all of the state west of the Blue Ridge as western Virginia, these three areas may be designated as the northwestern, central western, and southwestern portions of Virginia. In a general way, according to this somewhat arbitrary division, northwestern Virginia embraces that portion of the state north of the southern border of Rockingham county, while central western and southwestern Virginia are divided by the southern and southeastern borders of Roanoke and Craig counties. The boundaries of these three areas are indicated on the map, page 142.

GENERAL GEOLOGY OF NORTHWESTERN VIRGINIA.

The cement materials of this area are limited almost entirely to the Valley of Virginia, in which the major portion of the division is included. These materials occur in strata of Cambrian and Ordovician age, outcropping throughout the Valley and along the foothills of the bounding mountains. The Blue Ridge on the east is made up of quartzites and other rocks unsuited for cement manufacture, while North mountain and the Shenandoah mountain, occupying the portion of the state west of the Valley, are likewise composed of unsuitable rock. In the latter case the strata are sandstones, quartzites, and shales of Silurian and Devonian age.

In a general way the geology of this portion of the state is quite simple. North of Strasburg the Valley is broad, more or less level, and exhibits two belts of limestone separated by a belt of shale. This shale belt averages four miles in width and occupies the central portion of the Valley, its western edge passing just east of Strasburg and Winchester. The structure section across the Valley from the Blue Ridge to Little North mountain, about the latitude of Winchester, on page 68, illustrates the relation of the limestone and shales in this area. South of Strasburg, Massanutten mountain occupies the central portion of the Valley, extending southwest as far as the latitude of Harrisonburg. In this area also the general geology is comparatively simple and is shown by the structure section on the same page.

The most important geologic feature of this area, from an economic standpoint, is the great downfold of strata occupying the central part of the Valley. North of Strasburg the strata enclosed in this downfold or syncline have been worn down to the general level of the Valley, but south of this town a deep sag in this syncline brings the more resistant Massanutten quartzites below the general level of erosion of the neighboring

mountains. Thus when, as a result of subsequent erosion, the Great Valley was formed, Massanutten mountain, on account of its hard quartzites, was left as a ridge dividing the Shenandoah Valley. Because of the relation of Massanutten mountain to this downfold, this syncline has been called the Massanutten mountain syncline.

The Massanutten mountain syncline is of economic importance because, along its eastern and western sides, the pure and argillaceous Ordovician limestones are brought to the surface. The normal sequence of strata is usually exposed along the western edge, but on the eastern side, overthrust faulting is not uncommon. This faulting is not great but is usually sufficient to cut out the limestones of economic importance, the dolomitic strata being thrust upon the Upper Ordovician shales.

The long, narrow area lying between the Massanutten mountain syncline and the Blue Ridge is occupied by dolomitic limestones and shales which are described and located in the discussion of the stratigraphy. These strata are of no importance as a source of Portland cement rock, and this fact, combined with the lack of time for mapping, has caused the writer to leave them undifferentiated on the map. Just west of the great syncline, pure and argillaceous limestones occur in considerable abundance, but the central portion of the western half of the Shenandoah Valley is occupied mainly by the less valuable dolomitic limestone. The latter strata continue to the foothills of Little North mountain, where, when faulting has occurred, they may be found resting upon the Ordovician shales or upon still higher formations.

When the structure is normal along the western edge of the Valley, essentially the same sequence of strata may be observed as farther east, with the exception that here the strata of Trenton age contain a larger percentage of limestone than shales. In addition to the Massanutten mountain syncline, a few smaller synclines exposing the Ordovician shales and limestones have been noted in the Valley, but these are usually of slight consequence. The most important of these minor synclines lies just west of Harrisonburg and is described more in detail on a subsequent page.

STRATIGRAPHY.

The formations recognized by the Federal Survey in northwestern and central western Virginia are indicated in the generalized section shown in figure 2.

Period.	Formation Name.	Columnar Section.	Thickness in Feet.	Character of Rocks.	Character of Topography and Soils.
CARB.	Pocono sandstone.		700 +	Shale. Coarse sandstone of light color, with sandy shale and thin coal beds.	Sharp ridges, with thin, sandy, and rocky soils.
DEVONIAN	Hampshire formation.		1000–1400	Thinly bedded, gray and reddish sandstone, with more-massive beds of fine-grained sandstone, all interbedded with thin layers of shale.	High mountains, with thin, sandy soils.
	Jennings formation.		2900–3400	Shales, varying from olive color to buff, interstratified with massive, mainly fine-grained sandstone.	Mountain slopes and moderately high ridges, with thin, sandy soils.
	Romney shale.		600–1000	Dark shale, black below	Wide valleys and low, rounded ridges. Thin soils, usually clayey. The valleys usually contain alluvial deposits of varying width.
	Monterey sandstone.		0–300	Sandstone, in part calcareous.	Knobs and ridges along the base of higher hills.
SILURIAN	Lewistown limestone.		300–500	Cherty limestone. Pure limestone.	Knobby ridges and elevated valleys. Thin but rich soils.
	Rockwood formation.		150–300	Gray quartzite. Sandy shale.	Mountain slopes, overplaced by sandy soils.
	Massanutten sandstone.		500–600	Reddish sandstone. Gray quartzite. Red and gray sandstones.	High rocky ridges, with thin, sandy soils.
	Martinsburg shale.		600–1400	Gray shale, with sandy beds above and calcareous beds below.	Low, rounded hills in the Appalachian Valley, and the eastern slope of Little North Mountain. Thin, sandy clay-soils.
	Shenandoah limestone.		1800 +	Massive fossiliferous limestone. Cherty limestone. Dolomitic (magnesian) limestone, varying from light gray to dark gray.	Moderately steep ridges in the Appalachian Valley. The undulating surface of the Appalachian Valley, with clay-soils of variable depth.

Fig. 2.—Generalized section of area covered by the Staunton Folio, U. S. Geological Survey. (After N. H. Darton.)

Nearly all of the sedimentary rocks exposed in northwestern Virginia are of Cambrian and Ordovician age. The economic importance of the younger rocks and of the area occupied by them is so small, that they are not considered in the present description of the stratigraphy, although the character of their strata and of the soil and topography is noted in the

accompanying table. Four well defined groups of Cambrian and Ordovician rocks have been recognized in this part of the state, namely the sandstones, quartzites, and shales of Lower Cambrian age, the Shenandoah limestone belonging in part to the Cambrian and the Ordovician, the Martinsburg shale of the Middle and Upper Ordovician, and the Massanutten sandstone, hitherto regarded as Silurian, but now known to belong in part to the Ordovician. Of these four main divisions the Shenandoah limestone and Martinsburg shale only are of economic interest in cement manufacture, and therefore their subdivisions will be considered more in detail. The relations and general characters of these formations are expressed in the table on the following page (45).

Lower Cambrian Quartzites, Shales, and Sandstones.

The rocks of Lower Cambrian age outcrop only along the eastern edge of the Valley and form the western slope and foothills of the Blue Ridge. The highly siliceous nature of the sediments precludes their use in the manufacture of cement and they are briefly noted below simply to complete the description of the stratigraphy. A more detailed description of these formations may be found in the Harpers Ferry folio of the Geologic Atlas

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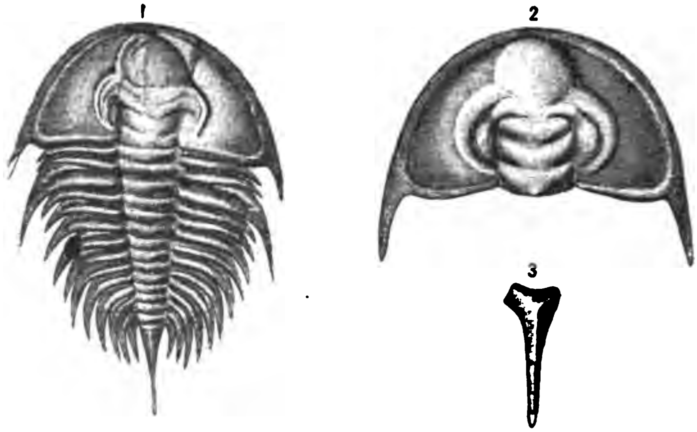


Fig. 3.—A characteristic lower Cambrian trilobite *Olenellus thompsoni* Hall. (After Walcott.)

1. An entire specimen, natural size. 2. Head of the individual, undistorted. 3. The spine-like pygidium.

Entire specimens of this trilobite are rare, but fragments, especially of the spines, are occasionally found in the lower Cambrian sandstone. Specimens of the same or a closely related species have been found in the Wautaga shale at Salem, Va.

Table of Cambrian and Ordovician formations for northwestern Virginia.

Age.	Group.		Name.	Thickness (feet).	Character of rock.
	Massanutten Sandstone.		Tuscarora quartzite (Richmond or Silurian)	300±	Coarse conglomerate and quartzite.
Up. Ordovician (Cincinnatian)			Juniata shales and sandstones (Lorraine).........	200±	Sandy, reddish shales and coarser sandstone.
	Martinsburg Shale.		Upper (Eden) shale.........	500±	Gray and buff sandy shales.
			Middle (Utica) shale.......	1000±	Dark gray or black fissile shale.
			Lower (Trenton) shale[a]...	100 to 300	Calcareous drab shales in lower half; more argillaceous strata in upper part.
Mid. Ordovician (Mohawkian)	Shenandoah Group.		Chambersburg limestone[a]..	400	More or less pure and argillaceous limestone and calcareous shales.
			Stones River limestone[a]...	900±	Heavily bedded dove and dolomitic limestone with purer dove strata in upper part.
Lower Ordovician (Canadian)		Natural Bridge.	Beekmantown limestone.	2300	Finely laminated massive bluish-gray magnesian and purer limestone with sandy cherts and some shale.
Saratogan (Upper Cambrian)			Conococheague limestone.	1500±	Dark blue magnesian limestone with limestone conglomerate at the base.
Acadian (Middle Cambrian)			Elbrook limestone......	3000±	Blue-gray dolomitic limestone, with some cherty limestone and red shale.
			Wautaga shale................	1250±	Reddish shales with mottled blue limestone and flaggy sandstone.
			Shady limestone[b]	1000±	White crystalline dolomite, gray magnesian limestone with occasional beds of argillaceous limestone and shale.
Georgian (Lower Cambrian)			Antietam sandstone.........	500±	Firm white sandstone and sandy shales.
			Harpers shale.........	1000+	Bluish-gray sandy shales.
			Weverton sandstone.........	100 to 900	Massive gray and white sandstone.
			Loudoun formation.	0 to 800	Slates, shales, sandstone, limestone and conglomerates.
Algonkian?			Catoctin schist................	1000+	Grayish-blue and altered diabase with masses of eruptive granite.

a Portland cement rock horizons. b Natur[illegible] rock horizons.

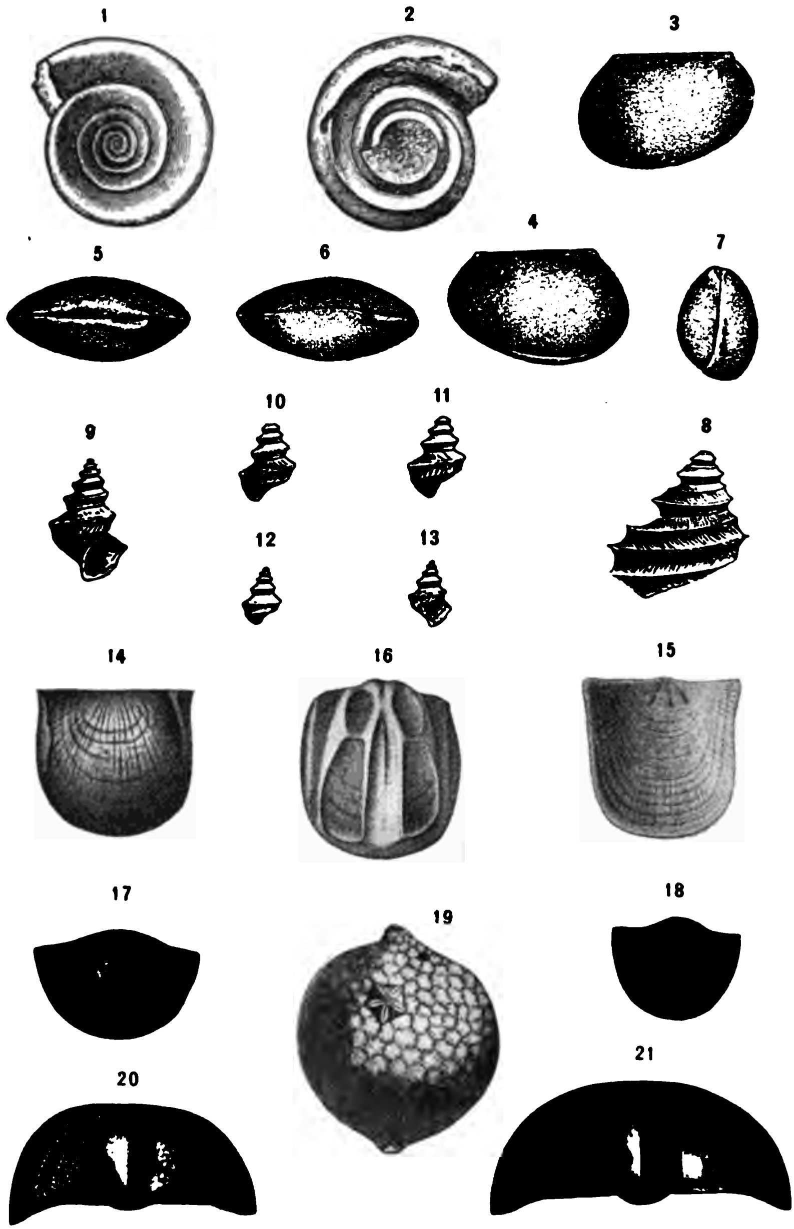
of the United States. The formations of Lower Cambrian age are in ascending order, the Loudoun formation, the Weverton sandstone, the Harpers shale, and the Antietam sandstone.

Loudoun formation.—Resting unconformably upon the pre-Cambrian Catoctin schist and other rocks making up the main mass of the Blue Ridge, is a formation consisting mainly of dark, slaty rocks, but including shales, sandstones, pure limestones, and conglomerates. The thickness varies from nothing to over 800 feet, this range often occurring within a short distance. The formation is typically exposed in Loudoun county, Virginia, whence its name. The pure limestone constituent occurs as lenses in the dark slate and would be of economic importance if better developed. These lenses have been worked for lime, but their chief value lies in the beds of marble along the line of their easternmost outcrop. The principal outcrops of these limestones and marbles are along the axis of South mountain and just west of Catoctin mountain. The eastern belt is thicker and more continuous, and in some places the marble bed reaches a thickness of about 50 feet. Transportation facilities are poor, however, and it will be some time before this rock will prove of economic importance.

Weverton sandstone.—This formation is based upon the massive gray to white sandstone and fine conglomerate outcropping prominently in South mountain near Weverton, Md. In Virginia the Weverton sandstone is confined to the Blue Ridge area, and in the main follows the westernmost high peaks of this region. The thickness varies from 100 to 900 feet, while the area occupied by its outcrops is of no value agriculturally or economically.

Harpers shale.—Outcropping along the Potomac river at Harpers Ferry are bluish gray sandy shales 1,000 feet or more in thickness, to which the above name has been applied. These strata are everywhere much twisted or cut off by faults, so that their true thickness cannot be determined. The Harpers shale is composed of argillaceous material containing many small grains of quartz and feldspar. Upon weathering their color changes to a light, greenish gray, while the soils produced by their decay contain enough clayey material to be of moderate value. The outcrops are limited mainly to a narrow band along the west flank of the Blue Ridge.

Antietam sandstone.—Following the Harpers shale are firm white sandstones and sandy shales about 500 feet thick which are well shown on the tributaries of Antietam creek, in Washington county, Maryland. The area occupied by this sandstone consists of a series of small patches just



CHARACTERISTIC FOSSILS OF THE BEEKMANTOWN, STONES RIVER AND CHAMBERSBURG FORMATIONS.

Unless otherwise stated, the figures on this plate are natural size, and are copied from various authors.

Beekmantown limestone.

Figs. 1, 2.—*Ophileta complanata* (Vanuxem). Two specimens about natural size. This or similar coiled gastropods are often found in the cherts of the Beekmantown limestone.

Stones River limestone.

Figs. 3–7.—*Leperditia fabulites* (Conrad).

3. Cast of the interior, × 2, showing impressions of the internal papillæ.

4–7. Right side, dorsal, ventral, and posterior views of an entire example, × 2.

Figs. 8–13.—Gastropods of the Stones River limestone. These fossils seldom weather out free, and the species are identified mainly from cross-sections in the rock.

8. *Lophospira serrulata* (Salter). View of a nearly perfect example of this beautiful shell.

9–13. *Lophospira perangulata* (Hall). Views of different specimens of this widely distributed and common species. It is distinguished by its small size and the absence of a carina on the upper end of the whorls.

Chambersburg formation.

Figs. 14–16.—*Christiania trentonensis* (Ruedemann).

14. Impression of outer surface of dorsal valve, × 2.

15. Ventral valve, × 2.

16. Interior of a dorsal valve showing the strong muscular markings.

Figs. 17, 18.—*Plectambonites pisum* (Ruedemann). Views of two examples, × 2, showing slight variations.

Fig. 19.—*Echinosphærites aurantium* (Hisinger). View, natural size, of a Russian example of this common cystid. American specimens are figured on Plate XXI.

Figs. 20, 21.—*Tretaspis reticulata* (Ruedemann). Cephalon, × 3, of this rather abundant species. The Virginia examples are, as a rule, larger than the New York specimen here figured, some of them equalling the figures in size.

EXPLANATION OF PLATE III.

west of the Blue Ridge. The abundance of sandstone fragments strewing the surface of its small area makes the soils of this formation unimportant agriculturally.

SHENANDOAH GROUP.

The siliceous deposits of Lower Cambrian age are succeeded by a great limestone group, first known as the "Valley" limestone and later, on account of its general occurrence in the Shenandoah Valley, as the Shenandoah limestone. These strata consist of blue, gray, and dove-colored massive magnesian limestone and dolomites, with purer and argillaceous limestone at the top of the group. In northwestern Virginia the exact thickness has not been accurately determined, although it is probably never less than 3,500 feet and often more than 5,000 feet. This same limestone forms the floor of the Appalachian Valley in general, and is found outcropping from New York to Alabama. In the north it is known under such local names as Lancaster or Kittatinny, while in southern Virginia and the states farther south it has been separated into a number of formations. Professor Campbell[a] has recently described five distinct divisions for central western Virginia. These are, in ascending order, (1) the Sherwood limestone of Lower Cambrian age, (2) the Buena Vista shale of Lower or Middle Cambrian age, (3) the Natural Bridge limestone, representing Middle and Upper Cambrian and Lower Ordovician, (4) the Murat limestone, and (5) the Liberty Hall limestone of Middle Ordovician age. In northwestern Virginia, divisions corresponding to the Sherwood, Buena Vista, and Natural Bridge formations may be distinguished, and, as these are undoubtedly the northern extension of the southern strata, the same names should be used. The Murat and Liberty Hall formations are distinct faunally and lithologically from the rocks occupying the same interval in the northern part of the valley, and were probably deposited in a separate basin. In northwestern Virginia the interval between the top of the Natural Bridge limestone and the bottom of the Martinsburg shale is occupied by two formations corresponding in a general way to the Stones River, Black River, and Lower Trenton divisions of the general time scale.

The name Shenandoah limestone was proposed as a geographical term in place of "Valley" limestone of the older geologists. The two names are thus synonymous, and, as the "Valley" limestone included all the strata between the Lower Cambrian siliceous rocks and the Upper Ordovician shales, the Shenandoah limestone likewise would apply to the same interval

[a] Amer. Jour. Sci. (4), XX, 1905, pp. 445–447.

in spite of the fact that the geologic succession might be quite different in various parts of the Great Valley. For example, in the typical and restricted area of outcrop—the Shenandoah Valley—this limestone, lithologically considered, could not include strata of Upper Trenton age, since these are shales forming the basal members of the overlying Martinsburg shale. In other portions of the Great Valley, the Trenton and even later formations are represented by limestones which would thus fall within the limits of the "Valley" limestone.

The importance of definitely locating the various formations, particularly of the upper part of the Shenandoah limestone, is understood when it is known that these latter strata are the most important sources of cement material in western Virginia. The well known Lehigh county cement rock of Pennsylvania is of Black River and Trenton age, and strata of similar age and physical character are found in the Valley of Virginia. The various subdivisions of the Shenandoah limestone are discussed below under the headings of Cambro-Ordovician and Middle-Ordovician limestones.

Cambro-Ordovician Limestones.

The divisions instituted by Professor Campbell in 1905 for the limestones of Cambrian and Lower Ordovician age in central western Virginia would have been used without change for the northwestern part of the state, had not a new set of names been proposed by Mr. G. W. Stose[a] for apparently the same strata in the Appalachian Valley of southernmost Pennsylvania. Mr. Stose surmised that the lower formations were alike in both areas, but since the matter was doubtful, and, moreover, a large fault and corresponding gap in the stratigraphy existed in the Harpers Ferry region, he proposed new names. The Ordovician portion of the northwestern Virginia section agrees accurately with the same interval in southern Pennsylvania, but more study is required before the correlation of the Cambrian rocks in the several areas can be satisfactorily made. Attention is called in the following paragraphs to the various names which have been applied to these strata.

Shady (Sherwood–Tomstown) limestone.—The lowest strata of the Shenandoah group are massive drab to white, impure limestones and dolomites. Near the base are beds of purer rock often burned for lime. Toward the top, cherty beds may be found, while the top itself is of purple shale and

[a]Sedimentary Rocks of South Mountain. Jour. Geol., XIV, No. 3, 1906, pp. 201–220.

red sandstone. In southern Pennsylvania these strata are known as the Tomstown limestone, the type area of outcrop being at Tomstown, a village near the foot of South mountain where, judging the thickness from the dip of the strata and the width of outcrop, approximately 1,000 feet may be found. Professor Campbell's earlier designation, Sherwood limestone, is from the railroad station of that name in Rockbridge county, Virginia, but a still earlier name for these same strata is the Shady[a] limestone of Tennessee.

Wautaga (Waynesboro–Buena Vista) formation.—The red to purple shale phase of the lower Shenandoah limestone is known under the name of the Waynesboro formation from its outcrop at Waynesboro, Franklin county, Pennsylvania. Here a thickness of about 1,200 feet occurs, which is double that of apparently the same shale in central western Virginia designated the Buena Vista shale. The greater part of the Waynesboro formation consists of siliceous purple shale and flaggy calcareous sandstone. At the base the rocks are quite massive and siliceous, while the flaggy sandstones are most common at the top of the formation. The upper sandy shales afforded Mr. Stose trilobites suggesting Middle Cambrian age, although apparently the same shales in central western Virginia contain the characteristic Lower Cambrian trilobite, *Olenellus*. The two names Waynesboro and Buena Vista are apparently synonymous, and the earlier, Buena Vista, might have been held had not this name been preoccupied. In view of these circumstances the name of the Tennessee formation, Wautaga shale[a], applied to the same stratigraphic interval, is adopted for these purple shales.

Elbrook limestone.—Following the Middle Cambrian Wautaga sandy purple shales are massive bluish gray dolomitic limestones possibly 3,000 feet thick, marked at the top of the formation by an unconformity indicated by conglomerates of rounded pebbles and "edgewise beds." These dolomitic strata make up the Elbrook limestone, named from a town in southern Pennsylvania where the formation is well shown in quarries. Fossils of Middle Cambrian age occur in the basal layers. Associated with the Elbrook limestone are red and green shales and sandy limestone, but these latter strata are only local in their development.

Conococheague limestone.—This and the preceding formation are readily separated in the field by the conglomerates mentioned above. These conglomerates are of rounded limestone pebbles an inch or more in diameter,

[a]Cranberry folio (No. 90), U. S. Geol. Survey.

in a matrix with numerous coarse quartz grains; or again they may consist of thin limestone fragments tilted at various angles, making up the strata known as "edgewise beds." The unconformable relations are further marked by oölites and limestones with uneven red clay partings. Above the basal conglomerates are about 1,500 feet of dark blue limestone, massive when freshly quarried but weathering into thin bands. The few fossils found in the Conococheague limestone in Pennsylvania are indicative of Upper Cambrian age.

Beekmantown limestone.—Finely laminated purer limestones 2,300 feet in thickness follow the somewhat siliceous Conococheague strata. The fossils, of which a considerable number has been found in southern Pennsylvania, indicate that these strata are to be correlated with the Beekmantown of New York, so the same name has been used by Mr. Stose. In Virginia silicified specimens of the gastropod *Ophileta complanata,* figured on plate III, have been found in the cherty débris of the Beekmantown limestone. This limestone is in turn succeeded by the dove-colored, purer strata of Middle Ordovician age.

The Elbrook, Conococheague and Beekmantown limestones occupy the stratigraphic interval of Professor Campbell's Natural Bridge limestone, and closer study may result in the recognition of these three divisions in the type area of the latter.

The estimated thickness of the Natural Bridge limestone in central western Virginia is about 3,500 feet. Northward the thickness increases until 7,000 feet may be measured in southern Pennsylvania. In northwestern Virginia the formations composing the Natural Bridge limestone are rather uniformly dolomitic, non-crystalline strata with few shale beds. About 1,500 feet below the top of the Shenandoah limestone, as measured by Darton, a sandy horizon is encountered. These sandstones are well developed along the eastern side of the Shenandoah Valley and also along the western side, particularly in the vicinity of Edinburg and Mt. Jackson. Above these sandstones occur cherty layers, while below, the usual dolomites are found. Fossil evidence from various horizons of the Natural Bridge limestone indicates that it contains strata of Middle and Upper Cambrian age in the lower division, while the upper or cherty portion is to be correlated with the Lower Ordovician (Beekmantown).

Economically considered, these Cambro-Ordovician limestones are of

Fig. 1.—Fine-grained, dark limestone, showing obscurely conchoidal splintery fracture. Nidulites bed of the Chambersburg formation, Strasburg, Va.

Fig. 2.—Fragment of massive dove-colored limestone. The color, fracture, and the calcite strings belonging to a single-tubed species of *Tetradium*, penetrating the rock, are especially characteristic.

Upper portion of Stones River formation, Strasburg Junction, Va.

LIMESTONES OF THE STONES RIVER AND CHAMBERSBURG FORMATIONS.

little importance. This is especially true in regard to their use as a cement rock, the magnesian content being too high, as the following analysis will show:

Analysis of Beekmantown limestone (upper portion) just west of Strasburg Junction, Va.

(J. H. Gibboney, Analyst.)

	Per cent.
Insoluble	10.06
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	1.00
Lime (CaO)	28.60
Calcium carbonate ($CaCO_3$)	51.07
Magnesia (MgO)	18.00
Magnesium carbonate ($MgCO_3$)	37.80
Total	99.93

GENERAL DISTRIBUTION OF CAMBRO-ORDOVICIAN STRATA.

To map these several formations accurately would have required more time for field work than was at the disposal of the writer, but in a general way their occurrence in northwestern Virginia is as follows: Along the eastern part of the Shenandoah Valley, that is, east of Massanutten mountain, the Elbrook, Conococheague, and Beekmantown formations are limited to the western two-thirds. Sometimes the dolomitic strata are found overthrust upon the Martinsburg shale brought up by the Massanutten mountain syncline, thus cutting out all of the Ordovician pure and argillaceous limestone. The eastern third of the Valley in this same region is usually occupied by the Wautaga shale and Sherwood limestone. In the Valley west of Massanutten mountain, the upper or cherty portion of the Beekmantown is more conspicuous, although the lower formations are sometimes brought to the surface by faulting. When the faulting is slight or absent, these cherts are found along a strip several miles in width, occupying approximately the center of the Valley. Where overthrust faulting has occurred, the dolomitic limestone may be traced to the western edge of the Valley, where they are thrust over the Martinsburg shale or still younger formations. Structure sections illustrating this general distribution are given in the following pages.

MIDDLE ORDOVICIAN LIMESTONES.

Following the Beekmantown formation in northwestern Virginia is a series of limestones, which, economically considered, are of the greatest importance. These are the Middle Ordovician limestones composed in large

part of argillaceous and highly calcareous strata. The succession of Middle Ordovician rocks in this part of Virginia is most clearly shown in the section given on page 77, commencing west of Strasburg Junction, Shenandoah county, and extending eastward to the vicinity of Strasburg. Here the western side of the syncline forming Massanutten mountain brings up the strata in regular order and excellent exposures may be found along the Southern railroad between the two places mentioned, and in the neighboring quarries and creeks. These upper limestones of the Shenandoah group are classed under the Stones River and Chambersburg formations, discussed in the following pages.

Stones River Formation.

Strata of this age have been recognized in many parts of the Mississippi Valley, and the formation is now known to be widespread. However, little has been published concerning the distribution of these rocks in the Appalachian Valley, so that the recognition of a thickness of 900 feet in northwestern Virginia is not without interest.

The formation was first described by Professor Safford as a distinct group[a] but later, in his "Geology of Tennessee" (1869), the name was abandoned under the misapprehension that the Stones River rocks were equivalent to the Trenton of New York. The group name was revived by Winchell and Ulrich in 1897[b], when these authors gave the most complete account of the strata that has yet been published.

In the central basin of Tennessee, the typical area of the Stones River formation, these strata comprise about 340 feet of light blue and dove-colored limestone. The lowest member, Murfreesboro limestone, is of heavily bedded, cherty layers; the next division, Pierce limestone, is a comparatively thin bed of shale and limestone crowded with bryozoa; the third member, Ridley limestone, is again heavily bedded, while the Glade limestone, the topmost division, is of flaggy dove limestone with thin shaly partings.

In the gorge of the Kentucky river at High Bridge, Ky., a considerable thickness of Stones River rock is exposed with the base not seen. In the Appalachian Valley of southern Pennsylvania, their thickness has increased to over 1,000 feet, and the strata, although still generaly dove-colored, are heavily bedded throughout. The following is a composite section of the

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[a] Amer. Journal Science (2), XII, 1851, p. 352.

[b] Geol. Nat. Hist. Surv. Minnesota, III, Pt. II, 1897, p. xc.

Stones River formation in the Mercersburg area of southern Pennsylvania, as published by Stose in 1908:

Composite section, Stones River formation, Mercersburg, Pa., area.

	Feet.
Thin-bedded, fine-grained, pure, dove limestone	275±
Massive, pure limestone containing *Maclurea* and black chert layers. Upper part, compact, blue to dark. Lower part, light gray, granular and oölitic	150–200
Massive and thin-bedded limestone interbedded with magnesian layers	600±
Total	1,050±

In Virginia, as in other portions of Pennsylvania, the cherty *Maclurea* horizon cannot be clearly distinguished.

Going south in the Valley, the thickness diminishes to approximately 900 feet at Strasburg, and finally, about half way between Harrisonburg and Staunton, Va., the formation is very thin and is overlapped by the Murat limestone which, in central western Virginia, usually succeeds the Natural Bridge limestone directly. This overlapping of the Murat limestone upon the Stones River formation gives a clue to the age of the peculiar fauna of the Murat and succeeding formations.

Lithologic characters.—The Stones River rocks in northwestern Virginia are in general heavily bedded dolomitic layers alternating with purer limestone strata. In color and texture the rock varies from fine-grained dove to a dense black with the dove-colored rock predominating. Many of the layers run as high in magnesia as the underlying Cambro-Ordovician limestone, but the Stones River formation differs in that at least a few pure dove limestone layers are found in almost every exposure. The pure limestone is most abundant at the top of the formation and this portion therefore is most extensively quarried. Many of these upper layers are penetrated by the thin calcite strings belonging to a single-tubed species of *Tetradium,* which, in connection with the smooth homogeneous groundmass and color of the main rock, gives it a very characteristic aspect from the lithologic standpoint. A sample of this limestone is figured on plate IV, figure 2. Another method of distinguishing the two formations lithologically lies in the character of the soil to which each gives rise on weathering. The soil resulting from the decomposition of the older limestone is of a deep red color, and generally contains a considerable number of chert fragments scattered through it. Stones River rocks, on the other hand, in weathering give very little chert, and areas underlaid by them may often be distinguished further by the fact that the resulting soil seems to be

particularly suited for the growth of cedar trees. Indeed, the presence of a considerable number of cedar trees in an area of Ordovician strata is quite a reliable sign that the underlying rocks are of Stones River age. This preference of cedars for Stones River areas is due, primarily, of course, to the nature of the rock itself, in this case, the pure dove strata being cedar-bearing. The extensive well known cedar glades of central Tennessee are located upon the pure, dove-colored Stones River limestone. In southwestern Virginia the pure dove limestones are most abundant in the lower members of the Chickamauga limestone referred to the Stones River and Tyrone formations, where the areas of outcrop are likewise marked by numerous cedars. (See plate XXII, figure 2.)

Paleontology.—Dove limestones are most abundant and in fact sometimes limited entirely to the Stones River formation in Virginia, but the most accurate method of determining rocks of this, as well as any other age, is by their enclosed fossils. Characteristic forms are figured on plate III, but of these the *Leperditia* is probably the only species that can be found well enough preserved for accurate determination. Some of the purer limestone layers are crowded with gastropods closely resembling the species figured. These cannot be broken out of the rock in good condition, but their cross sections indicate a general type of structure unlike and more advanced than the gastropods found in the underlying Beekmantown limestone. The latter, both in species and number, are exceedingly few, so that without a thorough search, fossils of any kind are unlikely to be found in the Beekmantown. A species of *Tetradium,* somewhat allied to *T. cellulosum,* figured on plate XXIII, is sometimes quite abundant in the Stones River strata, but unless weathered so as to show their structure, specimens are distinguished with some difficulty from other calcite strings in the rock.

Chemical composition.—Although the analyses of Stones River rocks show a considerable variation in lime and magnesia, still they can be divided into two general classes, the purer and the dolomitic limestones. The purer limestones are generally of fine-grained texture and of a dove color, although darker strata are sometimes interpolated. These dove and dark layers occur most frequently near the top of the formation, so that this portion may generally be depended upon to furnish the purer rock. With the exception of number II, all of the analyses in the table below are of samples from the upper portion. The lower strata of the Stones River formation often show a high percentage of magnesia and, less

Fig. 1.—A mottled blue limestone, the darker, smooth areas being highly argillaceous and fine-grained, while the lighter speckled matrix is of much purer composition, and consists largely of crystalline calcite. Middle portion of bed 3a, Strasburg section, Strasburg, Va.

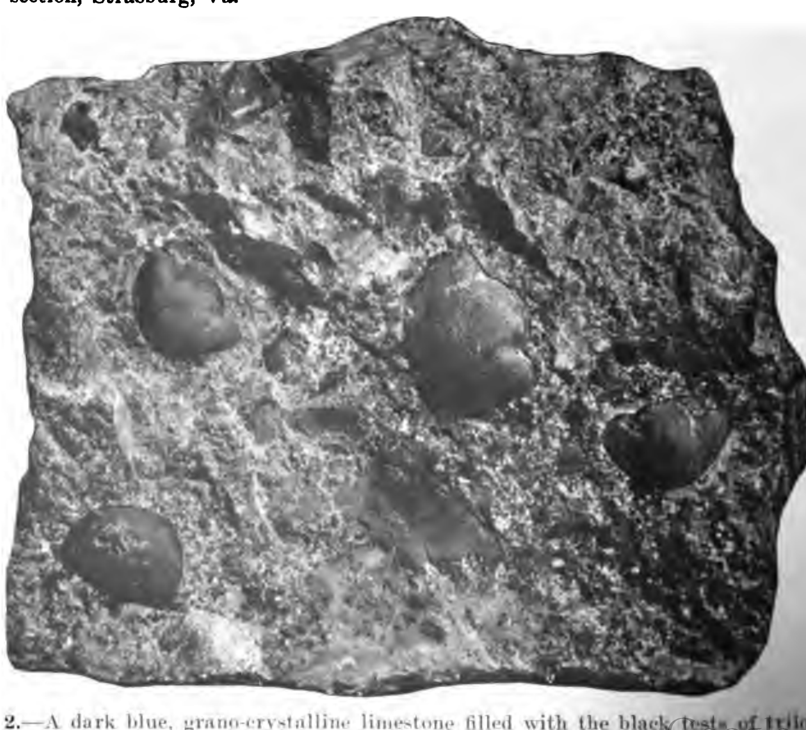


Fig. 2.—A dark blue, grano-crystalline limestone filled with the black tests of trilobites and small ostracods. Upper portion of bed 3a, Strasburg section, Strasburg, Va.

STONES OF THE CHAMBERSBURG FORMATION

commonly, of silica. Their value in the present connection therefore is correspondingly small. The analyses of the following table are repeated in succeeding pages where particular localities and sections are discussed.

Analyses of Stones River limestones in northwestern Virginia.

(J. H. Gibboney, Analyst.)

	I.	II.	III.	IV.	V.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Silica (SiO_2)	0.36	56.26	3.11	9.10	8.06
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3) }	0.08	4.82	0.64	1.32	1.14
Calcium carbonate ($CaCO_3$)	99.01	33.88	94.82	86.82	87.68
Magnesium carbonate ($MgCO_3$)	0.45	1.91	1.53	2.71	1.81
Total	99.90	96.87	100.10	99.95	98.69

I. Pure dove limestone, upper part of Stones River, Strasburg, Va.
II. Siliceous limestone, lower part of Stones River, Woodstock, Va.
III. Compact black layers in upper part of Stones River, Riverton, Va.
IV. Compact black limestone in upper part of Stones River, east of Harrisonburg, Va.
V. Dark blue splintery limestone, Stones River, Mt. Horeb Church, Va.

Chambersburg Formation.

About 400 feet of more or less pure and clayey limestones intervene between the top of the Stones River formation and the base of the Martinsburg shale in the vicinity of Strasburg and elsewhere in northwestern Virginia. Although these strata correspond in position to the Lowville (Birdseye), Black River, and early Trenton formations of New York, their lithologic and faunal differences were found to be so great that the new name Chambersburg[a] was proposed for their reception. The rocks of the Chambersburg formation are particularly well exposed in northwestern Virginia along the Massanutten mountain syncline, but the most detailed section is to be had at Strasburg. By reference to this section, given below, it will be noted that nine beds are distinguished, these varying in lithology from siliceous blue limestone through purer blue and dove limestone to argillaceous strata, and finally, at the top, calcareous shales. These various beds are discussed more fully under the description of Shenandoah county, so that detailed accounts of each need not be introduced at this point.

The best exposures of the following section are in the quarries at Stras-

[a]Stose, Journal of Geology, XIV, 1906, p. 211.

burg Junction and in the creek and railroad cuts between this place and Strasburg. Structure sections through this region are given under the discussion of Shenandoah county, page 77.

Geologic section in the vicinity of Strasburg, Va.

	Feet.
4. Martinsburg shale (upper Trenton, Utica, and Eden). Gray and black shales, calcareous at the base, then more argillaceous, passing upward into sandy layers	2,000
3. Chambersburg (Lowville, Black River, and early Trenton) formation. About 400 feet of blue and argillaceous limestone arranged in the following order:	
(i) Earthy gray limestone and calcareous shales with numerous fossils, *Tretaspis*, *Christiania*, and several species of *Plectambonites* occurring most abundantly	40
(h) Light gray earthy limestone, no fossils observed	30
(g) Massive dove limestone holding numerous specimens of a large species of *Nidulites*	65
(f) Rather thin-bedded dove limestone with *Nidulites* rare	60
(e) Thin-bedded dark gray argillaceous limestone	52
(d) Thin-bedded argillaceous black limestone	22
(c) Nodular argillaceous dark blue limestone with numerous fossils of which *Solenopora*, several species of *Phylloporina*, *Echinosphaerites*, and *Christiania*, are especially abundant	30
(b) Crinoidal limestone	10
(a) Crystalline blue limestone, cherty in the upper part but pure in lower part, bryozoa abundant but a species of *Subulites* is especially characteristic of this bed	80
Total thickness of Chambersburg formation	389
2. Stones River formation. About 900 feet of more or less pure and magnesian limestones, the upper 100 feet consisting of heavily bedded, pure dove limestone (90 to 97 per cent. $CaCO_3$) with occasionally a black layer. In the vicinity of Strasburg Junction these beds are extensively quarried for lime. The remaining strata consist of heavily bedded alternately arranged layers of pure and magnesian limestone. The presence of abundant gastropods of Stones River types and the characteristic fossils *Tetradium* cfr. *cellulosum* and *Leperditia fabulites* in the uppermost layers determines the age of this formation.	
1. Typical Beekmantown dolomitic limestone weathering into characteristic chert.	

Generalized section.—As stated before, the detailed section exposed so well at Strasburg cannot be made out in its entirety at many other places; so the following generalized section is introduced for the recognition of the rocks in any part of northwestern Virginia. The thicknesses given in this section are those observed at Strasburg, where the rocks are believed to be best developed. Therefore it must be remembered that in other localities, considerable departure from these figures may be observed:

Fig. 1.—Weathered surface of rather pure limestone, largely made up of specimens of *Girvanella*. These low organisms show in the photograph as light-colored, concentrically marked areas. Basal bed of Chambersburg formation at Strasburg, Va.

Fig. 2.—Fragment of highly argillaceous limestone or calcareous shale. Topmost layer of Chambersburg formation at Strasburg, Va.

LIMESTONES OF THE CHAMBERSBURG FORMATION.

Generalized section of the Chambersburg formation in northwestern Virginia.

(Martinsburg shale of upper Trenton, Utica, and Eden age at top.)

		Feet.
4.	Gray earthy limestone with numerous fossils in upper part	70
3.	Thin-bedded to massive dove and black limestone holding *Nidulites* in more or less abundance	125
2.	Nodular and thin-bedded gray argillaceous limestone with numerous fossils in lower third	104
1.	Pure limestone with cherty portions	90
	Total	389

The more persistent members of the Chambersburg formation are the massive dove and crystalline limestones holding *Nidulites* in abundance (bed 3), and the argillaceous limestones in which *Tretaspis* and *Christiania* are especially characteristic fossils (bed 4). These two divisions may be recognized in almost every section, but the other members are seldom so well shown as at Strasburg.

Bed 4 was recognized at practically every outcrop of the Chambersburg formation and seems to be its most persistent member. As far south as Fort Defiance in Augusta county it was still found, but here the thickness had apparently diminished greatly. Moreover, at this locality it rested upon the Murat limestone, which in turn overlapped upon a thin bed of Stones River rock, thus indicating the relations between the rocks of northwest and central western Virginia as here subdivided. Portions of bed 4 approach a cement rock with an ideal chemical composition more nearly than any of the other divisions of the Ordovician limestone. Some of the upper layers of bed 4 are of calcareous shales indistinguishable except by their fossil contents from the overlying Martinsburg shale (see plate VI, figure 2). A fragment of calcareous shale with cystid remains, from another portion of the upper bed, is figured on plate VIII.

The southernmost exposure of bed 3 noted was at Harrisonburg, but more careful search will probably reveal its presence south of that city. The comparatively low dip of the rocks forming the eastern limb of the syncline just west of Harrisonburg causes the exposure of bed 3 in this region to be relatively wide. Along the western side of the Massanutten mountain syncline the dip is steeper and the width of the outcrop is therefore much less. From the viewpoint of the cement manufacturer, these dove limestones can be relied upon to furnish the purer rock for mixture. With the dove strata are homogeneous, fine-grained black layers showing

an obscurely conchoidal fracture. Specimens of *Nidulites* are often very abundant upon the surface of these layers, a specimen of which is figured on plate VII.

The lowest beds of the Chambersburg formation seem to be best developed in the northernmost part of the state. In the Strasburg section, ninety feet have been assigned to this portion. Compared with higher beds, all of the rock is comparatively pure, but a few cherty layers are present. Two samples of this division are illustrated on plate V. The basal layer of this division is often crowded with specimens of *Girvanella,* as indicated on plate VI. These low organisms have all the appearance of concretions or pebbles, and give a conglomeratic aspect to the bed.

Paleontology.—The fauna of the Chambersburg formation embraces a large number of genera and species, some of which, in America, are limited almost entirely to the eastern portion of the Appalachian Valley. The general assemblage of forms seems to have more relations with those found in the rocks of the same age in Europe than with the faunas of the Mississippi Valley sections. Of this Appalachian Valley fauna, probably the most striking and characteristic form is the ball cystid or *Echinosphærites,* which is probably identical with a species from the Ordovician rocks of Russia. This fossil occurs in great numbers at many places in the Appalachian Valley and at first glance resembles a concretion more than an organic body. However, a blow of the hammer will break away some of the plates with which the globose body is covered, and show the organic nature of the specimen. The specimens found in the Appalachian Valley are usually larger than the Russian example figured on plate III, but the shape and general arrangement of the plates is the same. In order to make certain of the cystid nature of these concretion-like fossils, it is only necessary to examine one of the plates under a hand lens, when their radial structure can be clearly seen.

A second highly characteristic fossil of the Chambersburg formation is the trilobite *Tretaspis,* of which the same or a closely related species is figured on plate III. The three node-like divisions and the reticulate surface make this easy of recognition.

Numerous brachiopods occur, but the most abundant are a species of *Christiania* and a *Plectambonites.* These have been found in almost every exposure of the argillaceous members of the Chambersburg, and the shape and surface marking of the two shells serve very well in identifying the horizon.

Another fossil common in the Strasburg region is the peculiar *Bolboporites*, a small, globose, coral-like organism, while *Nidulites*, another peculiar type, is common everywhere in the more calcareous strata.

Associated with the forms enumerated are numerous species of bryozoa and of other classes, but it is believed that the above will serve to identify the strata.

Essentially the same fauna has been described by Ruedemann[a] from a conglomerate inclosed in the Normanskill shales at Rysedorph Hill, Rensselaer county, New York. This conglomerate is composed of pebbles of Lower Cambrian, Beekmantown, Chazy, and early Trenton ages, the fossils of the last named being in marked contrast with any other American fauna. Dr. Ruedemann supposed that these early Trenton pebbles were derived from the regions to the east and northeast, but the place of outcrop was unknown. It is, therefore, of much interest to find the strata in place in Pennsylvania and Virginia. The following is a partial list of this fauna in northwestern Virginia:

Echinosphærites cf. *aurantium*.
Nidulites cf. *favus*.
Bolboporites sp.
Girvanella.
Solenopora compacta.
Hindia sphæroidalis.
Stomatopora inflata.
Stomatopora delicatula.
Phylloporina, several species.
Hemiphragma cf. *irrasum*.
Batostoma sp.
Stictoporella sp.
Leptæna cf. *rhomboidalis*.
Plectambonites pisum.
Plectambonites asper.
Christiania trentonensis.
Dalmanella cf. *subæquata*.
Dalmanella cf. *hamburgensis*.
Skenidium cf. *merope*.
Triplesia n. sp.
Conotreta sp.
Orbiculoidea sp.
Rafinesquina cf. *incrassata*.
Bollia sp.
Eurychilina sp.
Aparchites sp.
Ampyx sp.
Tretaspis reticulata.
Harpina sp.
Sphærocoryphe cf. *robustus*.
Illænus cf. *americana*.
Isotelus sp.

Analyses—A considerable variation in the composition of the various strata composing the Chambersburg formation is to be expected because of their diverse natures. Still these strata in general terms can be divided into (1) more or less pure, dark or dove-colored compact limestones, and

[a]Trenton Conglomerate of Rysedorph Hill and its Fauna. Bull. 49, New York State Museum, 1908, pp. 1–115.

(2) into dark, argillaceous limestone. Upon this classification, the analyses of these rocks in northwestern Virginia have been arranged and presented below.

Analyses of more or less pure, compact limestone, Chambersburg formation, in northwestern Virginia.

(J. H. Gibboney, Analyst.)

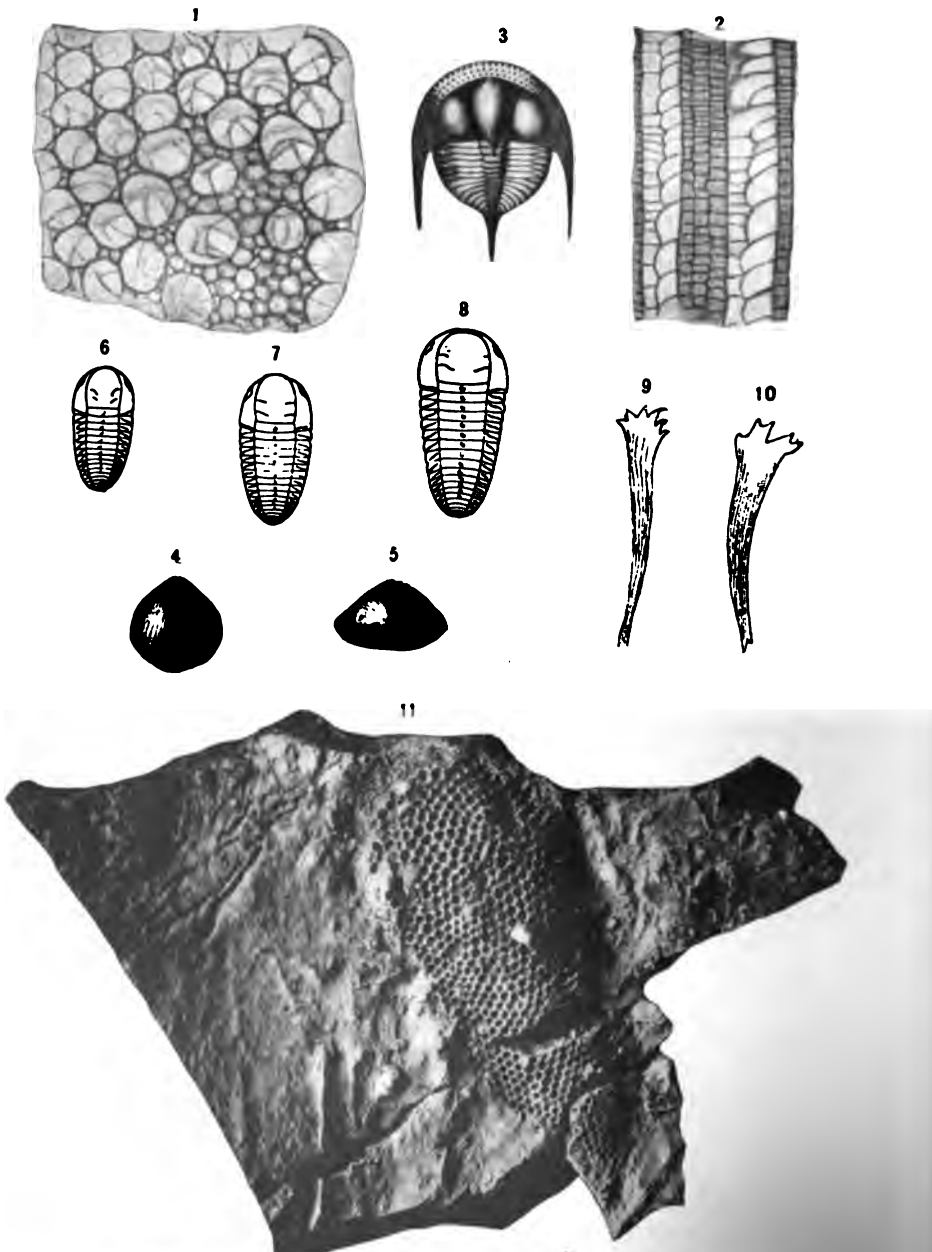
	I.	II.	III.	IV.
	Per cent.	Per cent.	Per cent.	Per cent.
Silica (SiO_2)	2.32	43.50	12.10	8.68
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	0.24	5.50	1.48	1.32
Calcium carbonate ($CaCO_3$)	96.43	47.86	84.64	88.71
Magnesium carbonate ($MgCO_3$)	1.09	2.18	1.68	1.34
Total	100.08	99.04	99.90	100.15

	V.	VI.	VII.	VIII.
	Per cent.	Per cent.	Per cent.	Per cent.
Silica (SiO_2)	10.04	4.60	8.68	30.72
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	1.46	0.56	0.94	3.52
Calcium carbonate ($CaCO_3$)	86.57	92.00	90.36	62.78
Magnesium carbonate ($MgCO_3$)	1.54	2.79	0.41	0.71
Total	99.61	99.95	100.39	97.73

	IX.	X.	XI.
	Per cent.	Per cent.	Per cent.
Silica (SiO_2)	12.82	15.32	4.04
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	1.84	1.34	1.80
Calcium carbonate ($CaCO_3$)	81.07	82.35	85.40
Magnesium carbonate ($MgCO_3$)	2.52	0.21	8.36
Total	98.25	99.22	99.60

I. Unusually pure blue limestone, lower part of formation, Strasburg, Va.
II. Siliceous blue limestone, lower part of formation, Strasburg, Va.
III and IV. Dove limestone, middle part of formation, Strasburg, Va.
V. Dark blue limestone, lower part of formation, Woodstock, Va.
VI and VII. Dark blue compact limestone, Harrisonburg, Va.
VIII and IX. Semi-crystalline limestone, Harrisonburg, Va.
X and XI. Dark blue limestone, Mt. Horeb Church, Va.

These analyses and those following are here brought together for the comparison of the chemical constituents of these and other strata. As mentioned before, the analyses are repeated in their proper places elsewhere.



FOSSILS OF THE CHAMBERSBURG, TRENTON, AND UTICA FORMATIONS.

Figs. 1-5.—Characteristic fossils of the lower third (Trenton horizon) of the Martinsburg shale.

1, 2. *Prasopora simulatrix* (Ulrich). Tangential and vertical sections, × 18, of the eastern variety of this very common, massive, hemispheric bryozoan. The features shown in sections may be observed with a hand lens upon the specimens, especially when fractured and moistened.

3. *Trinucleus concentricus* (Eaton). An entire example of this trilobite, somewhat magnified. The three nodes and pitted head shield are the portions most frequently found.

4, 5. *Zygospira recurvirostris* (Hall). Dorsal and cardinal views of an ordinary specimen, × 3.

Figs. 6-8.—*Triarthrus becki* (Green). The characteristic fossil of the Utica shale. Outlines of three specimens of this species.

Figs. 9, 10.—*Corynoides calicularis* (Nicholson). A peculiar graptolite found in great profusion in some of the lowest beds of the Martinsburg series. Two examples of these cylindrical chitinous bodies enlarged about 5 diameters.

Fig. 11.—A rather complete specimen, × 2, of *Nidulites*, partially embedded in the rock. Nidulites bed of the Chambersburg formation, at Strasburg, Va.

Figures 1 to 10 are copied from various authors.

EXPLANATION OF PLATE VII.

Analyses of dark, argillaceous limestones, Chambersburg formation, northwestern Virginia.

(J. H. Gibboney, Analyst.)

	I.	II.	III.	IV.	V.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Silica (SiO_2)...............	19.78	12.00	14.88	18.20	15.88
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3) }	1.88	2.26	2.38	8.00	0.92
Calcium carbonate ($CaCO_3$).	74.28	84.21	80.36	70.00	82.75
Magnesium carbonate ($MgCO_3$)	0.82	1.13	2.18	2.00	99.99
Total....................	96.76	99.60	99.80	98.20	99.54

	VI.	VII.	VIII.	IX.
	Per cent.	Per cent.	Per cent.	Per cent.
Silica (SiO_2).........................	16.34	23.24	37.06	14.68
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3) }	7.49	3.22	3.60	1.88
Calcium carbonate ($CaCO_3$)............	74.14	71.07	57.46	81.71
Magnesium carbonate ($MgCO_3$).........	1.00	1.72	1.47	0.05
Total..............................	98.97	99.25	99.59	98.32

I and II. Gray, argillaceous limestone, middle and upper part of formation, Strasburg, Va.
III. Argillaceous limestone, upper part of formation, Woodstock, Va.
IV. Argillaceous limestone, Mt. Jackson, Va.
V. Argillaceous limestone, Riverton, Va.
VI. Argillaceous limestone, 5 miles east of Woodstock, Va.
VII. Argillaceous limestone, Harrisonburg, Va.
VIII. Argillaceous limestone, 3 miles west of Montevideo, Va.
IX. Knotty, argillaceous limestone, Mt. Horeb Church, Va.

Martinsburg Shale.

No sharp break occurs between the argillaceous limestones and calcareous shales forming the upper part of the Chambersburg formation and the overlying Martinsburg shale. From an economic standpoint no arbitrary line of separation need be given, since the lowest beds of the Martinsburg shale are as highly calcareous as the topmost part of the preceding formation. Paleontologically, however, the two divisions may be separated by the total absence of the characteristic Chambersburg fossils in the succeeding shales.

In general it may be said that the lowest deposits of the Martinsburg shale are fine, calcareous to argillaceous shales, dark drab in color when

fresh and yellowish when weathered. Higher up in the series, brown or black micaceous shales are encountered, while toward the top the rocks become more siliceous. The thickness varies considerably, but in this part of Virginia 700 to 1,000 feet expresses the variation, although in other regions as much as 3,000 feet have been measured.

Three divisions of the geological time scale are represented in the Martinsburg shale. These are in ascending order (1) Upper Trenton, (2) Utica, and (3) Eden. Although the actual lines delimiting these divisions are difficult if not almost impossible to determine, yet in a general way it may be remarked that the lower calcareous portion is of upper Trenton age, the brown or black shales are Utica, and the upper shales or siliceous portion belongs to the Eden. For convenience of reference to these different parts of the Martinsburg shale, the three terms, lower, middle and upper divisions are used here, but with no present intention of recognizing these divisions as separate formations or as mapable units.

The Martinsburg shale weathers into a yellow and brown clay soil which is in marked contrast to the red soil of the limestone areas.

Lower (Upper Trenton) shales.—The portion of the Martinsburg shale series of Trenton age consists of calcareous and argillaceous strata of a dark drab color, with a thickness as yet undetermined. The thickness is probably over 100 feet and less than 300, but undoubtedly varies considerably in different areas. Considered from an economic standpoint, the Trenton phase of this shale series need not be distinguished from the underlying Chambersburg shales and argillaceous limestones, as both will prove of use in cement manufacture.

Paleontologic characters.—Paleontologically the Trenton phase is of interest on account of the graptolite fauna, species of which are figured on plate VII. This fauna is not that of the typical Trenton rocks of the Mohawk Valley of New York but belongs to the Appalachian province, which, as indicated elsewhere in this report, contained a very different assemblage of organisms from that of the Mississippi Valley province. Some of the shales are fairly crowded with individuals of the peculiar graptolite *Corynoides.*

Distribution.—The main outcrops of the lower shale are parallel with and contiguous to the Chambersburg formation. The exposures in northwestern Virginia are therefore along the flanks of the Massanutten mountain syncline. Their more detailed distribution is noted in the discussion of the several counties crossed by this syncline.

Analyses.—The following analyses of shales from the Trenton horizon of the Martinsburg shale show such a high percentage of lime that the rock, chemically at least, may be considered as an argillaceous limestone with a higher silica content than usual. These analyses also indicate a close similarity in composition of rock from the same geologic horizon but from distant localities.

Analyses of calcareous shales, Trenton horizon of Martinsburg shale.

(J. H. Gibboney, Analyst.)

	I.	II.
	Per cent.	Per cent.
Insoluble	27.60	30.56
Alumina (Al_2O_3) Iron oxide (Fe_2O_3)	3.36	3.82
Calcium carbonate ($CaCO_3$)	66.97	61.07
Magnesium carbonate ($MgCO_3$)	1.22	3.44
Total	99.15	98.89

I. Strasburg, Virginia.
II. Harrisonburg, Virginia.

Lower (Trenton) limestones.—Along the western side of the Appalachian Valley in northwestern Virginia the Chambersburg formation is followed by thin-bedded limestones with interbedded dark shales instead of the dark calcareous or argillaceous shales just described. The surface of these limestones is often covered with fossils characteristic of the Trenton formation. The development of limestones and shales instead of shales alone, along this portion of the Valley, is of importance in that an additional cement rock is furnished. Unfortunately the geologic structure and transportation facilities are such that at present little development of this rock could be expected. As stated in the description following, the dolomitic limestones are generally thrust upon the Martinsburg shales or higher formations along the western side of the Valley, thus cutting out the strata of economic value. Again, in most instances where the geologic succession is normal, facilities are lacking. However, this limestone must be accounted as one of the cement resources, and analyses of the rock are therefore introduced on the following page.

Analyses of limestone and shale, Trenton horizon of Martinsburg shale, Mt. Horeb Church, Va.

(J. H. Gibboney, Analyst.)

	I.	II.
	Per cent.	Per cent.
Insoluble	27.44	7.80
Alumina (Al_2O_3), Iron oxide (Fe_2O_3)	4.06	0.90
Calcium carbonate ($CaCO_3$)	65.89	90.64
Magnesium carbonate ($MgCO_3$)	0.15	1.04
Total	97.54	100.38

I. Shale bands between limestones.
II. Thin-bedded compact limestone.

Middle (Utica) shale.—This and the succeeding upper (Eden) shale are two of the most constant divisions of the geologic succession of western Virginia, and with careful search the characteristic fossils of both may be found in sections exposing the upper two-thirds of the Ordovician shales.

In comparison with the preceding shales the amount of calcareous material in this middle division has been greatly diminished so that, except for mixture, the rock will probably never prove of much use as a cement material. In view of the large amount of calcareous and argillaceous strata underlying the Utica shale the necessity for its use need not arise; therefore there is little occasion for considering it as a cement rock. However, an analysis is introduced at this point for comparison with the associated strata.

Analysis of shale, middle division of Martinsburg shale, Mt. Horeb Church, Va.

(J. H. Gibboney, Analyst.)

	Per cent.
Insoluble	43.94
Alumina (Al_2O_3), Iron oxide (Fe_2O_3)	5.18
Calcium carbonate ($CaCO_3$)	46.93
Magnesium carbonate ($MgCO_3$)	0.07
Total	96.12

EXPLANATION OF PLATE VIII.

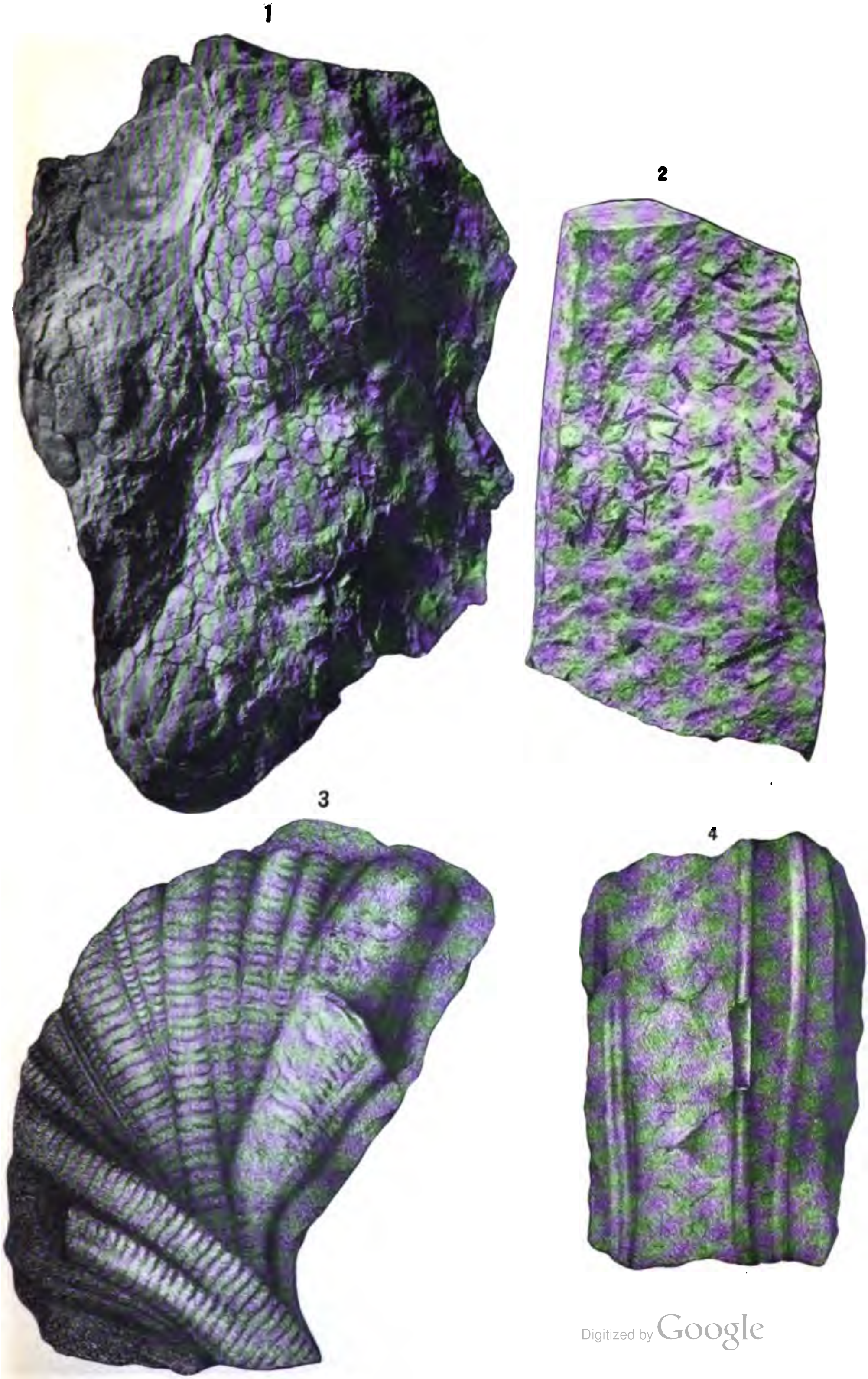
Fig. 1.—Fragment of calcareous shale from the Chambersburg formation. This shale often holds great numbers of crushed specimens of the ball cystid *Echinosphaerites*. The particular specimen here figured is from bed 3i of the Strasburg section at Strasburg, Va.

Fig. 2.—Grayish shale with graptolites from the basal part of the Martinsburg shale, Strasburg, Va. The larger serrate forms are of a species of *Climacograptus*, while the small, slender specimens are *Corynoides calicularis*, of which enlarged views are given on another plate.

Figs. 3, 4.—Characteristic fossils of the Clinch and equivalent sandstones. (After Hall, Natural History of New York, Paleontology II, 1852, Plate III.)

3. *Scolithus verticalis* (Hall). Natural size. These burrows are composed of smooth round stems penetrating the strata vertically. The species has been observed mainly in the smooth, fine-grained sandstone of the Clinch and the equivalent Appalachian sandstones. Similar forms occur in the lower Cambrian quartzites of Virginia, but the present species may usually be distinguished by its smaller size. In case of doubt, further search will usually result in the discovery of *Arthrophycus alleghaniensis* if the sandstone is the Clinch.

4. *Arthrophycus alleghaniensis* (Harlan). Natural size. This highly characteristic fossil has been described and figured under the above name, as well as *Harlania harlani*, but it is probably most often illustrated as *Arthrophycus harlani*. At various times this fossil has been considered the cast of a sea weed, a worm, as inorganic, or as animal trails. The recent and very ingenious work of Sarle, however, demonstrates the burrow nature of Arthrophycus. In Virginia this fossil has been observed at numerous localities, but, similar to its occurrence in New York, the simple or branching vermiform, transversely corrugated ridges are found apparently only on the under surface of homogeneous sandstone layers, resting in shaly partings.



CHARACTERISTIC FOSSILS OF THE CHAMBERSBURG FORMATION.

Fold in Massanutten (Tuscarora) sandstone. Panther Gap, Va.
(Photo by N. H. Darton.)

ANTICLINE IN MASSANUTTEN SANDSTONE.

Upper (Eden) shale.—Following the few feet of shales at Cincinnati, Ohio, holding characteristic Utica fossils, occur 250 feet of thin limestones and shales before strata of Lorraine age are reached. For these the term Eden, defined by Orton in the first volume of the "Geology of Ohio," is used in the Cincinnati area. These beds contain a prolific fauna, and are essentially blue limestone and shales. Proceeding eastward these beds become more arenaceous until in the Appalachian Valley sandy limestone and shales have taken the place of the purer limestones of the west. On account of the Appalachian coal field this change cannot be traced continuously, but the relations of the strata and their fossil contents prove the correctness of the correlation beyond a doubt. A few of the characteristic Eden fossils found in the Appalachian region are figured on plate XIV.

Because of the high silica content, the Eden shales of the Appalachian Valley are of no value as a source of cement material.

Massanutten Sandstone.

The crest of Massanutten mountain is usually composed of red, yellow, and white sandstone and quartzite, which, on account of their conspicuous occurrence here, were named as above. The Massanutten sandstone is divisible into two members, corresponding in a general way to the Bays sandstone and Clinch sandstone of the southern Appalachians. The lower member is 200 or more feet in thickness and consists of micaceous sandy shales, coarse sandstone and conglomerate. Portions of this division contain the characteristic Bays sandstone fossils figured on plate XIV, thus indicating the Lorraine age in terms of the general time scale. Fragments from the cliffs of overlying quartzite generally obscure this member so that good exposures are few. One of the localities where fossils may be found is at Buzzard's Roost at the northeast end of Massanutten mountain.

The upper Clinch equivalent of the Massanutten sandstone is made up of coarse conglomerates and quartzites, varying greatly in thickness but reaching a total of at least 500 feet. Fossils are scarce, although the characteristic *Arthrophycus alleghaniensis* and *Scolithus* figured on plate VIII may be found upon careful search.

In Pennsylvania and northwestern Virginia these two members of the Massanutten sandstone have been mapped as the Juniata and Tuscarora respectively. Neither member is of interest from the standpoint of cement materials.

GEOLOGY AND CEMENT MATERIALS OF INDIVIDUAL COUNTIES.

INTRODUCTORY STATEMENT.

In the following pages an outline of the general geologic features of each county is presented, followed by remarks upon the cement materials. Under the caption of the "Details of Localities," the intention is to discuss the more favorable places in each county showing good exposures of the pure and argillaceous limestones, and to give geologic sections of the strata and analyses of average rock samples. In indicating advantageous sites for cement plants, the writer means simply to imply that the cement rock and pure limestone deposits occur at the places mentioned, and that transportation facilities are at hand. Whether good cement can be made from the raw materials found at these places is a matter which can be determined only by experimentation on a commercial scale. The argillaceous limestones, in many instances, have a composition very similar to good cement materials of other regions, but this does not necessarily indicate that they also will make first-class cement.

It is also to be understood that, unless otherwise stated, all discussions of cement rock in this report refer to the use of the material in the manufacture of Portland cement.

FREDERICK COUNTY.

The cement materials of Frederick county consist of pure and argillaceous limestones of Ordovician age, restricted almost entirely to its eastern half. These limestones occur in two well defined bands entering the state at the northeastern corner of the county and continuing southwestward. The easternmost of these bands follows the western limb of the Massanutten mountain syncline. The pure limestones are almost entirely restricted to the Stones River formation, while the argillaceous limestones and calcareous shales occur in the Chambersburg formation and in the lower part of the overlying Martinsburg shale. This eastern line of outcrop passes just east of Winchester and west of Stephens City and Middletown, and is followed closely by the Cumberland Valley railroad and the Valley branch of the Baltimore and Ohio railroad. A number of quarries for the burning of lime have been opened in the Stones River formation along the railroad in the southern part of the county. The many cedar trees of this region are almost invariably found growing upon areas occupied by the Stones River formation.

The western line of outcrops follows the foothills of Little North mountain, and passes near or through the villages of Green Spring, Cedar Grove, Nain, Chambersville, Fawcett's Gap, and Wheatfield. Here, however, the full sequence of strata is not always found on account of the faulting to which the region has been subjected. This faulting is greatest in the northern half of the county, but in the southern half, the area south of Chambersville, the full sequence is generally found. That portion of the Shenandoah Valley between the two lines of outcrop just described is occupied mainly by the dolomites of Upper Cambrian and Lower Ordovician age, which, on account of their high percentage of magnesia, are of no value for cement purposes.

Both pure and argillaceous limestones are abundant at many localities along the eastern line of outcrop, and with the railroads practically following this line, the supply of rock and the transportation facilities are of the best. The analyses cited below show that much of the rock might be utilized for the making of Portland cement.

The western half of Frederick county is occupied mainly by Devonian shales which, in the absence of nearby suitable limestones, cannot be considered of any value as a cement material.

Geologic Structure.

When compared with other parts of the Shenandoah Valley, the geologic structure of the Valley portion of Frederick county is quite simple. The extreme eastern portion is occupied by the Massanutten mountain syncline, which here brings the Martinsburg shale to the surface, while the underlying Chambersburg and Stones River formations outcrop in regular order along its edges. The Valley west of this is occupied by an anticline exposing the Beekmantown dolomites mainly, and the foothills of Little North mountain again show the higher limestones and shales. Unlike other portions of the Valley, overthrust faulting is infrequent and is confined mainly to the western line of outcrops. This faulting also is generally very slight, so that in most places the full sequence of the rocks can be observed. In the northern half of the Valley portion of the county, normal faulting is encountered, especially near the eastern shales area. This faulting is more pronounced northward in the vicinity of Martinsburg, W. Va., but in the area under discussion is seldom great enough to entirely cut out one or more formations.

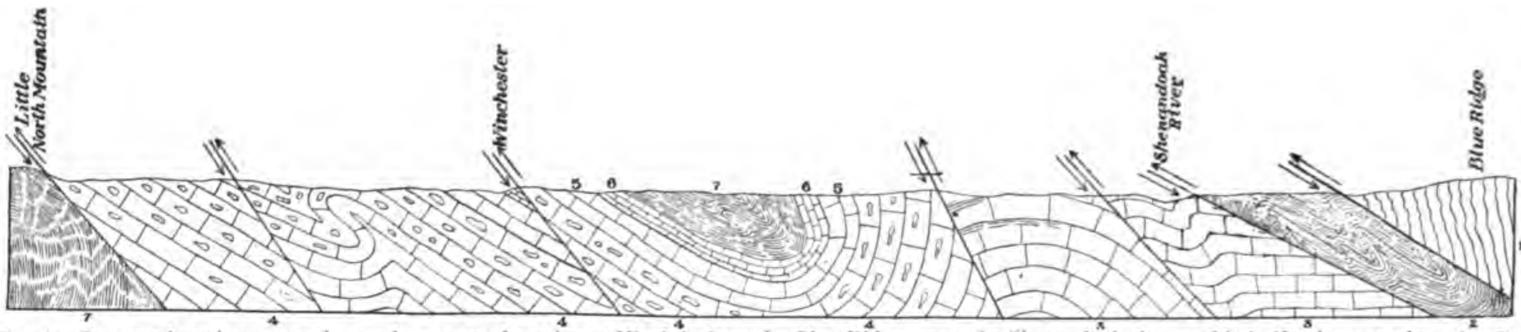


Fig. 4.—Structural section across the northern part of northwest Virginia from the Blue Ridge across the Shenandoah river to Little North mountain. 1. Pre-Cambrian strata of the Blue Ridge; 2. Lower Cambrian shales; 3. Cambrian limestone; 4. Cherty Cambrian and Ordovician limestone (Natural Bridge); 5. Pure and magnesian dove Ordovician limestone (Stones River); 6. Dark, compact and argillaceous Ordovician limestone (Chambersburg); 7. Martinsburg shale series.

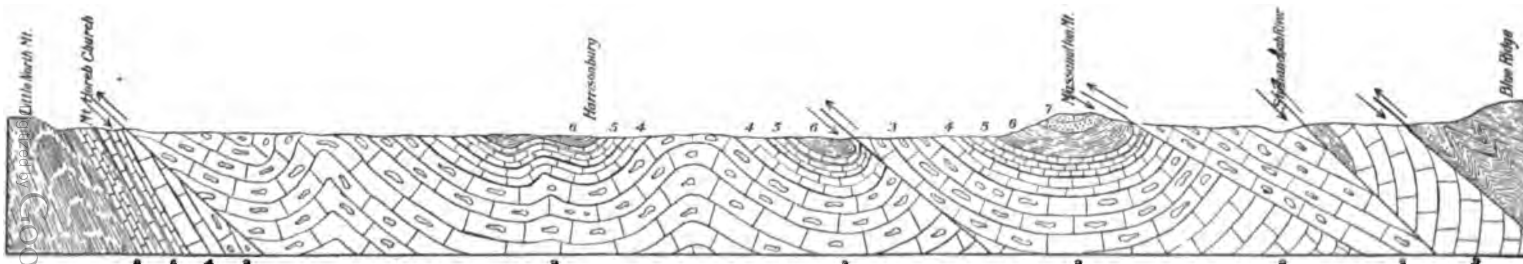


Fig. 5.—Structure section across Valley in the southern part of northwestern Virginia from the Blue Ridge to Little North mountain, about the latitude of Harrisonburg. 1. Pre-Cambrian strata of the Blue Ridge; 2. Cambrian limestone; 3. Natural Bridge limestone; 4. Stones River limestone; 5. Chambersburg formation; 6. Martinsburg shale series; 7. Massanutten sandstone.

Details of Localities.

Winchester.—Although the full geologic structure in the vicinity of Winchester could not be determined because of lack of continuous exposures, the quarries and other outcrops just west and east of the town indicate that by faulting a band of Lower Ordovician dolomitic limestones has been interpolated between a band of Stones River limestones on the west and argillaceous limestones and shales of Chambersburg and Martinsburg age on the east. The Stones River limestones can usually be determined, as mentioned before, by the growth of cedar trees along their outcrop, and although in this area these limestones are often dolomitic, the pure bands that do occur will prove to be the only source of rock high in lime. The magnesian portion of the Stones River formation in the vicinity of Winchester is a grayish, lustreless, unfossiliferous rock, weathering yellowish upon exposure to the atmosphere. The purer portion of the same formation is made up of dove or bluish limestone often showing outlines of small gastropoda upon the worn surfaces. These purer strata weather into a bluish white rock easily distinguished from the more magnesian variety. The same strata are also often mottled and exhibit streaks of apparently more clayey material arranged parallel to the bedding plane. In some parts of the section the purer and more magnesian strata alternate, and are present in about equal proportions. Besides gastropoda, bird's-eye markings of a species of *Tetradium* are common in the purer strata. East of the town the argillaceous limestones and calcareous shales can be found in considerable abundance, although exposures are not common. The following analysis shows that this argillaceous limestone, with a proper admixture of shale, can be used as Portland cement material:

Analysis of argillaceous (Chambersburg) limestone, just east of Winchester, Va.

(J. H. Gibboney, Analyst.)

	Per cent.
Insoluble	14.78
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	2.72
Lime (CaO)	44.94
Calcium carbonate ($CaCO_3$)	80.25
Magnesia (MgO)	0.34
Magnesium carbonate ($MgCO_3$)	0.71
Total	98.46

The composition of three samples of magnesian limestone from the vicinity of Winchester has been published by Professor Rogers in his "Geology of the Virginias." Judging from the locality, these specimens were selected from the Beekmantown limestone:

Analyses of limestones (Beekmantown), vicinity of Winchester, Va.

	I.	II.	III.
	Per cent.	Per cent.	Per cent.
Calcium carbonate ($CaCO_3$)	80.60	88.64	57.24
Magnesium carbonate ($MgCO_3$)	14.48	9.60	28.80
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	1.68	0.12	1.56
Silica (SiO_2)	2.68	1.30	11.68
Water	0.56	0.44	0.72
Total	100.00	100.10	100.00

I. Bluish gray, compact limestone from near Winchester on turnpike west of town.
II. Pale gray, compact limestone from same locality.
III. Gray blue, semi-granular limestone from northwest turnpike, 1 mile west of Winchester.

Localities north of Winchester to the state line.—Practically the same rock and method of faulting may be observed in this region as at Winchester and at Martinsburg, West Virginia, still farther north. On account of this, no samples were taken for testing, but the following description of the rocks in the vicinity of Martinsburg is introduced to show the limestone resources of the northeastern part of Frederick county. In the vicinity of Martinsburg, the pure limestones of Stones River age have been extensively quarried for flux, as indicated in the following notes, but these rocks, as well as the overlying argillaceous limestones and shales, can also be utilized as cement materials:

"At Martinsburg, W. Va., this limestone is exceptionally pure and very thick. It has been quarried there on a vast scale by the Standard Lime and Stone Company for use as flux in the iron furnaces about Pittsburg.

"The limestone outcrops in a belt extending southward from the town. On the east side is a low ridge of Hudson [Martinsburg] shale containing graptolites of Utica age near the base.

"Dipping at an angle of 20 degrees under these beds are 90 feet of dark, compact, crystalline and shaly limestones bearing fossils of Trenton age. Below this are three or four heavy beds of pure limestone averaging 15 to 20

feet in thickness, with a total of about 80 feet. This is the deposit that is quarried. The upper bed is a very massive, compact, light-gray limestone, weathering chalky white on the surface, with smooth fracture and but slight indications of bedding. The lower beds are darker, coarser grained, not so homogeneous, and have a rough fracture, and at the base are thinner bedded. The only fossils observed in these beds are a few *Leperditia* found in the upper layers, indicating Lowville (Birdseye) age.

"The whole of this mass is quarried, and is stated to average 98 per cent. carbonate of lime. The two samples tested by the Geological Survey contained 96.2 and 97.7 per cent. The limestone is quarried in an open cut 200 to 250 feet wide and 80 to 100 feet deep, the workable depth depending upon the amount of stripping that is profitable. The open cut extends for over 1½ miles along the strike and is being worked along its entire length. The same beds apparently continue beyond, to the south, and there is every reason to believe that they also occur along the strike north of the town. The rock is taken out on tram cars, is crushed to 5-inch size, and is loaded directly into the railway cars on the track. The reason that the stone can be profitably shipped such a distance is that the cars which transport the coal from the Pennsylvania mines to the south return loaded with limestone, thus avoiding an empty return run, and the freight rates are reduced to a minimum. It is reported that from 20 to 50 carloads a day of the crushed rock are shipped. With a quarry face of 80 feet and the dip of the rocks 20 degrees, the estimated output of the quarry per mile is about 3,000,000 tons."[a]

Stephens City.—The Martinsburg shale and the underlying argillaceous, pure, and dolomitic limestones, are well developed in the vicinity of Stephens City, especially just to the west where outcrops are not infrequent. The purer limestones have practically the same composition as those of the Stones River formation at Martinsburg, W. Va., while the argillaceous portions are very similar to those found in the vicinity of Winchester. On account of this similarity, no analyses are given.

Middletown.—This and the neighboring town of Meadow Mills are favorably located so far as transportation facilities and an abundance of cement materials are concerned. The following section taken along the street west from the depot at Middletown gives the sequence of rocks in this region, the highest beds being found farthest east. The section, part of which is covered or otherwise obscured, is as follows:

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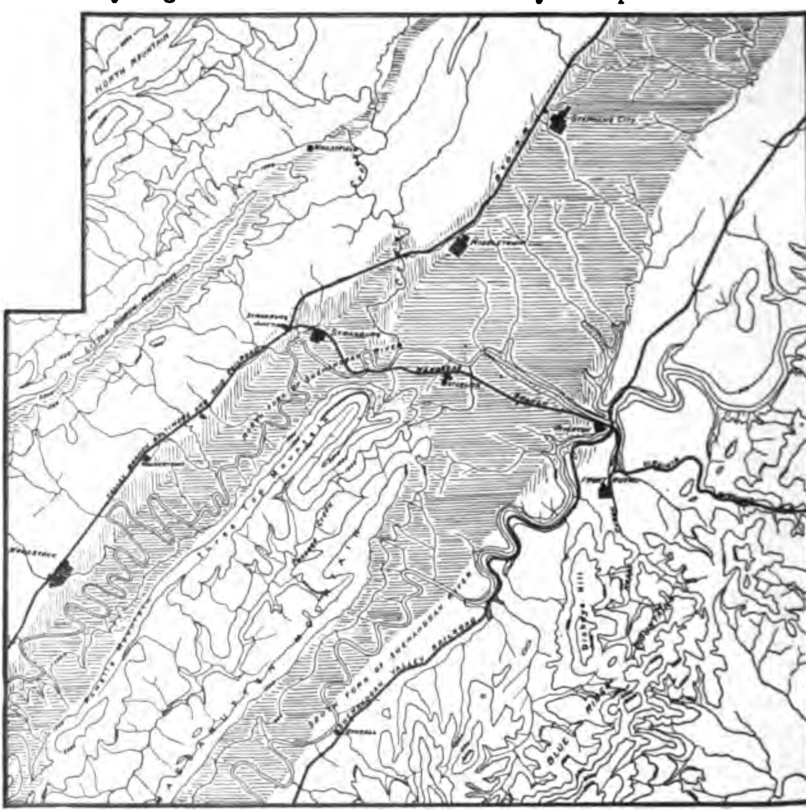
[a] Stose, Bull. U. S. Geol. Survey No. 225, pp. 516–517.

Section of Ordovician rocks in the vicinity of Middletown, Va.

	Feet.
Martinsburg shale:	
Mainly covered but apparently all calcareous shale	100
Chambersburg formation:	
6. Mainly covered but showing traces of earthy limestone	150
5. Partially covered, bluish limestone at the top and earthy or nodular limestone at intervals	100
4. Nodular limestone with specimens of *Echinosphærites* near the base	20
3. Arenaceous shale	20
2. Not exposed	30
1. Dark gray to black limestone with chert	38
Stones River formation:	
2. Massive dove limestone, apparently the same bed as that quarried for lime at Strasburg	40
1. Mainly magnesian limestone but with a few layers of pure limestone.	



Ordovician limestones. Ordovician shales.

Fig. 6.—Map showing distribution of cement materials of northwestern Virginia.

This section then continues westward, the magnesian and pure limestones of the Stones River formation being shown in a small anticline between Middletown and Meadow Mills, until in the vicinity of the latter place the higher, pure and argillaceous limestones are again exposed in a small syncline. Practically the same section is exposed in the vicinity of Strasburg in Shenandoah county, but in more detail. The latter section is given on another page.

Western edge of the Valley.—With railroad facilities so near the line of eastern outcrop of cement material, the pure and argillaceous limestones outcropping along the western side of the Valley are at present practically of no value. Here, however, considerable material may be found having the requisite qualities for use in making cement. The geologic section is essentially the same as that given along the eastern band, and little variation in the rocks is to be noted. On account of this similarity and the present unimportance of the region, no samples for analysis were taken.

CLARKE COUNTY.

This county affords two sources of cement material. On the extreme western edge of the county the eastern limb of the Massanutten mountain syncline exposes the calcareous portion of the lower part of the Martinsburg shale and the pure and argillaceous limestones of Stones River and Chambersburg ages. All of these outcrops, with the exception of a single locality discussed below, are at some distance from the two lines of railroads running through the Valley, so that their importance is at present slight. The physical characters of the rock and the analyses of the same are quite similar to those given for Riverton in Warren county, just to the south. The second source of cement material lies in the more or less pure and clayey limestones of Lower Cambrian age found along the eastern side of the Valley. These, however, have been used hitherto only for the manufacture of a natural cement and their discussion is deferred to the chapter on that subject. Analyses of these latter rocks are given below.

Wadesville.—The middle Ordovician limestones exposed along the eastern edge of the Massanutten syncline are crossed by the railroad in Clarke county at but a single locality. This is at Wadesville in the northwestern corner of the county. However, for a short distance north of this place the line of outcrop of these limestones is not far from the railroad, and to the south and west for 1½ miles the two parallel each other, so that this county affords an abundance of suitable limestones within short

distances of transportation facilities. The black argillaceous limestones are especially well shown along the road just east and west from the railroad station. The following section was observed along this road and on the farm of John M. Lock, starting about half a mile east of Wadesville and ending at Opequon creek on the west. The strata dip at an angle of about 40° northwestwardly.

Geologic section, Wadesville, Va.

	Feet.
Martinsburg shale:	
Gray, black, and olive shales	—
Chambersburg formation:	
Dark blue and black, compact argillaceous limestone	400
Coarsely crystalline grayish blue limestone	70
Stones River formation:	
Gray, dolomitic limestone with intercalated pure dove-colored layers, base not observed. These Stones River limestones have much the same characters described for the formation in other sections of this part of Virginia. The only strata of economic importance are the intercalated dove-colored pure limestones. The rock may be identified by its numerous *Tetradium* markings and by the presence of the ostracod *Leperditia fabulites*	—
Beekmantown limestone:	
Gray dolomitic, cherty limestone. These strata show comparatively few outcrops in this particular section but the presence of the rock can be detected by the more or less numerous chert fragments left upon weathering	—

As elsewhere, the beds of the Chambersburg formation are of the most importance in the present consideration, as they will be the sources of whatever rock may be used for Portland cement. The upper division is a massive, rather pure limestone with some of the layers crowded with the peculiar organism *Strephochetus*. The same strata occur at the base of the Chambersburg formation in the Strasburg section (see page 56), and, as analyses of that rock indicate, the lime content is high. These particular strata therefore, together with the dove limestone of the underlying Stones River formation, can be relied on as a source of pure limestone for mixture with highly argillaceous rock. Bed 4 embraces the typical cement rock of Ordovician age and is a uniform, dark, compact argillaceous limestone. The lower portion is massive but the upper part is less so and weathers into a shaly rock. The latter may be distinguished from the succeeding Martinsburg shale, which it somewhat resembles when weathered, by the higher percentage of lime as well as by the fossil contents. As in other sections, the ball cystid *Echinosphærites* characterizes this bed. At Wadesville specimens occurred sparingly throughout the bed, but are most numerous in the upper part.

Natural Cement Rock.

The limestones of the eastern part of the county are of value for the manufacture of natural cement, and a number of analyses from strata in this general region have been published by Professor Rogers. These bands of natural cement rock pass nearby Millwood and Berryville in Clarke county, and continuing northward are well exposed near Charlestown and Shepherdstown in Jefferson county, West Virginia, where they have long been burned for natural cement. Analyses of the Shepherdstown rock are as follows:

Analyses of limestones, vicinity of Shepherdstown, W. Va.

<table>
<tr><th></th><th>I.</th><th>II.</th><th>III.</th><th>IV.</th></tr>
<tr><td></td><td>Per cent.</td><td>Per cent.</td><td>Per cent.</td><td>Per cent.</td></tr>
<tr><td>Calcium carbonate ($CaCO_3$)</td><td>15.94</td><td>16.76</td><td>67.50</td><td>23.90</td></tr>
<tr><td>Magnesium carbonate ($MgCO_3$)</td><td>6.49</td><td>11.76</td><td>8.36</td><td>24.36</td></tr>
<tr><td>Alumina (Al_2O_3)
Iron oxide (Fe_2O_3)</td><td>0.64</td><td>0.35</td><td>7.00</td><td>2.10</td></tr>
<tr><td>Silica (SiO_2)</td><td>6.50</td><td>0.77</td><td>12.60</td><td>42.90</td></tr>
<tr><td>Water</td><td>0.12</td><td>0.13</td><td rowspan="2">4.54</td><td rowspan="2">6.74</td></tr>
<tr><td>Loss</td><td>0.31</td><td>0.23</td></tr>
<tr><td>Total</td><td>30.00</td><td>30.00</td><td>100.00</td><td>100.00</td></tr>
</table>

I. Fine-grained, lead gray, compact limestone.
II. Dark-colored compact limestone.
III. White limestone of fine texture.
IV. Light gray limestone with rather slaty fractures.

Similar strata in the vicinity of Charlestown showed the composition indicated below:

Analyses of limestone, vicinity of Charlestown, W. Va.

<table>
<tr><th></th><th>I.</th><th>II.</th></tr>
<tr><td></td><td>Per cent.</td><td>Per cent.</td></tr>
<tr><td>Calcium carbonate ($CaCO_3$)</td><td>38.66</td><td>8.48</td></tr>
<tr><td>Magnesium carbonate ($MgCO_3$)</td><td>9.50</td><td>6.58</td></tr>
<tr><td>Silica (SiO_2)</td><td>42.50</td><td>13.20</td></tr>
<tr><td>Iron oxide (Fe_2O_3)</td><td>2.00</td><td rowspan="2">1.20</td></tr>
<tr><td>Alumina (Al_2O_3)</td><td>1.50</td></tr>
<tr><td>Water and loss</td><td>5.84</td><td>0.56</td></tr>
<tr><td>Total</td><td>100.00</td><td>30.00</td></tr>
</table>

I. Coarse-grained, light gray limestone, near Charlestown.
II. Dull, earthy limestone from Evitt's Run, 3½ miles from Charlestown.

The same or very similar natural cement strata pass west of Harpers Ferry. Three analyses of this rock, given by Professor Rogers, are quoted below. The occurrence of purer strata among the dolomitic layers is indicated in analysis II.:

Analyses of limestone, vicinity of Harpers Ferry, W. Va.

	I.	II.	III.
	Per cent.	Per cent.	Per cent.
Calcium carbonate ($CaCO_3$)	53.88	95.86	81.16
Magnesium carbonate ($MgCO_3$)	43.40	1.46	10.80
Silica (SiO_2)	1.68	1.83	6.68
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	0.48		0.52
Water	0.56	0.85	0.84
Loss			
Total	100.00	100.00	100.00

I. Semicrystalline light gray limestone, 2 miles southwest of Harpers Ferry.
II. Coarse-grained light gray limestone, 4 miles west of Harpers Ferry.
III. Flesh-colored, semicrystalline, slaty limestone, near Harpers Ferry.

SHENANDOAH COUNTY.

The more valuable limestones of Shenandoah county are of Ordovician age, and restricted almost entirely to the foothills of the western side of Massanutten mountain. The corresponding rocks, which in Frederick county to the north are also found along the foothills of Little North mountain on the western edge of the Valley, are entirely cut out by an overthrust fault throughout the greater part of the same line in Shenandoah county. A small strip along Little North mountain in the northwestern part of the county, and a still smaller band in the southwestern corner, are the only places where an approximately normal sequence of the strata can be found on this side of the Valley. On the opposite side just west of Massanutten mountain, however, numerous exposures of good material can be found along a line passing in a northeast-southwest direction through Strasburg, Woodstock, just east of Edinburg and Mount Jackson, and Newmarket. The finest exposures are in the vicinity of Strasburg and Woodstock, and as the railroad facilities are also most convenient at these places, more complete descriptions and analyses of the various strata outcropping near these towns are given.

Strasburg.—The abundant pure and clayey limestones outcropping in the vicinity of Strasburg, combined with its railroad facilities, make this

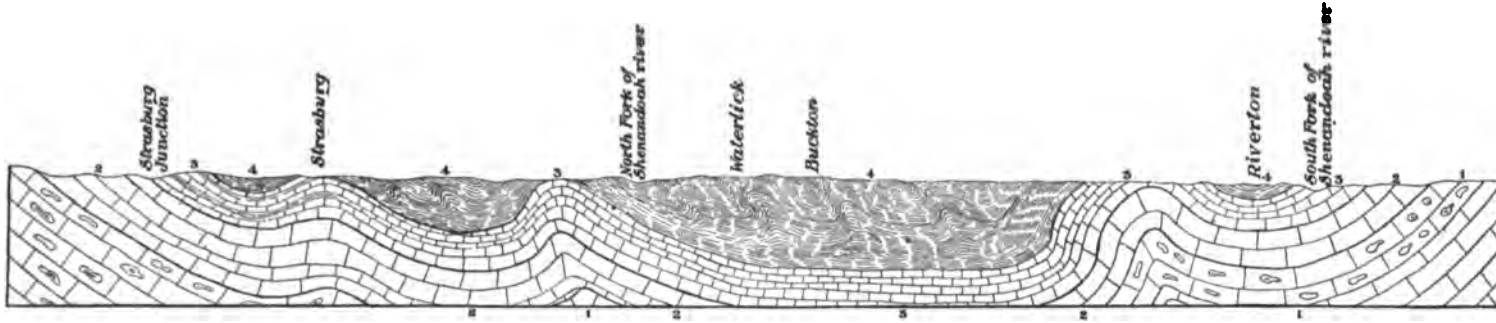


Fig. 7.—Structure section across Massanutten mountain syncline, just north of Massanutten mountain, from a point in the Valley east of Riverton to the vicinity of Strasburg Junction. 1. Cherty Natural Bridge limestone. 2. Pure and magnesian Stones River limestone. 3. Limestone of the Chambersburg formation. 4. Martinsburg shale series.

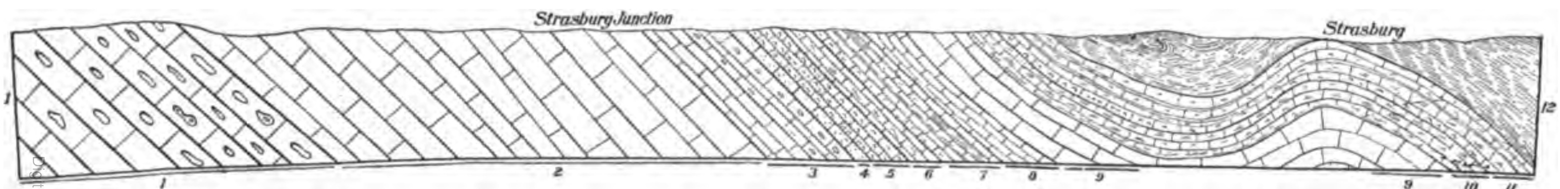


Fig. 8.—Structure section from Strasburg to a point about one mile northwest of Strasburg Junction, showing strata in detail: 1. Natural Bridge dolomite. 2. Stones River limestone. 3-11. Chambersburg formation. 3. Siliceous blue limestone, 80 ft. 4. Crinoidal limestone, 10 ft. 5. Nodular dark blue limestone, 30 ft. 6. Argillaceous black limestone, 22 ft. 7. Thin-bedded gray argillaceous limestone, 52 ft. 8. Thin-bedded dove limestone, 60 ft. 9. Massive dove limestone, 65 ft. 10. Earthy limestone, 30 ft. 11. Earthy limestone and calcareous shale, 40 ft. 12. Martinsburg shale.

one of the most promising sites for cement manufacture. As shown on the map, page 72, the line of outcrop of Martinsburg shale passes through Strasburg, so that east of the town an abundance of shale may be found, while to the west occur the various limestones. The rocks of economic importance outcrop between the town and Strasburg Junction, a mile or more to the west, where the upper part of the Stones River formation is being quarried and burned into lime. The following section is found exposed mainly between the two localities mentioned, although the lower beds of the Stones River and the Beekmantown limestones outcrop west of Strasburg Junction. The rocks dip to the east and are encountered in ascending order as Strasburg is approached. This section has been given in more detail under the discussion of the general geology of northwestern Virginia, but is repeated here in a brief form for ready reference with the analyses:

Geologic section in the vicinity of Strasburg, Va.

		Feet.
4.	Martinsburg shale	——
3.	Chambersburg formation. About 400 feet of blue and argillaceous limestones arranged in the following order:	
	(i) Earthy gray limestone and calcareous shales	40
	(h) Light gray earthy limestone	30
	(g) Massive dove limestone	65
	(f) Rather thin-bedded dove limestone	60
	(e) Thin-bedded dark gray argillaceous limestone	52
	(d) Thin-bedded argillaceous black limestone	22
	(c) Nodular argillaceous dark blue limestone	30
	(b) Crinoidal limestone	10
	(a) Siliceous blue limestone, cherty in the upper part but pure in the lower portion	80
2.	Stones River formation, about 900 feet of more or less pure and magnesian limestones, the upper 100 feet consisting of heavily bedded, pure dove limestone, with occasional black layers, alternating with magnesian limestone	900
1.	Typical Beekmantown dolomite, weathering into the characteristic chert...	——

Description and analyses. Bed 1.—No analyses of the rocks of this group are given for the reason that the strata run so high in magnesia that they are seldom of value as cement material. These rocks consist mainly of dolomitic limestone and exposures are not frequent. The presence of the rock, however, may be determined usually by the abundant fragments of chert into which it weathers. The resistant action of this chert is so great that although no outcrop of the rock itself may be seen, numerous small ridges throughout the Valley composed of chert alone may be encountered.

Bed 2. Stones River formation.—The 900 or more feet of limestones which make up this formation differ from the preceding rocks lithologically in the greater abundance of pure limestones, although a considerable part of the formation is, like the preceding, composed of magnesian limestone. In the Strasburg area the upper 100 feet of the Stones River formation contain the purer limestones which are usually dove-colored, but occasionally black layers running high in lime are found. These strata running high in lime are quarried for lime at Strasburg Junction. The following analysis by Dr. Henry Froehling is of rock from these layers:

Analysis of dove limestone from upper part of bed 2, Strasburg Junction, Va.

	Per cent.
Silica (SiO_2)	0.36
Alumina (Al_2O_3), Iron oxide (Fe_2O_3)	0.08
Calcium carbonate ($CaCO_3$)	99.01
Magnesium carbonate ($MgCO_3$)	0.45
Total	99.90

The value of this rock as a source of lime is evident from the above analysis, and its possible use for mixture with cement rock is also apparent.

Bed 3a.—The 80 feet of blue limestone composing this bed may be divided into two portions, an upper siliceous phase, and a lower, purer in lime. An average sample from the lower 40 or 50 feet gave the following analysis:

Analysis of blue limestone, lower part of bed 3a, Chambersburg formation, near Strasburg, Va.

(J. H. Gibboney, Analyst.)

	Per cent.
Insoluble	2.32
Iron oxide (Fe_2O_3)	0.24
Lime (CaO)	54.04
Calcium carbonate ($CaCO_3$)	96.43
Magnesia (MgO)	0.52
Magnesium carbonate ($MgCO_3$)	1.09
Total	100.08

The large amount of silica, or insoluble matter, in the upper strata of this division precludes its use as a cement material. This portion of the bed yields considerable chert on weathering and the lithological aspect of the rock also indicates its siliceous nature.

Analysis of siliceous, blue limestone upper part of bed 3a, Chambersburg formation, near Strasburg, Va.

(J. H. Gibboney, Analyst.)

	Per cent.
Insoluble	43.50
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	5.50
Lime (CaO)	26.80
Calcium carbonate ($CaCO_3$)	47.86
Magnesia (MgO)	1.04
Magnesium carbonate ($MgCO_3$)	2.18
Total	99.04

Bed 3b.—The 10 feet of limestone of this bed are composed almost entirely of crinoidal fragments and a freshly fractured surface shows numerous plates and stems of this class of organisms. As is usually the case with crinoidal limestone, the rock runs very high in lime.

Beds 3c-3e.—As far as good cement rock is concerned, the 30 feet of nodular, dark blue limestone of bed *c*, the 22 feet of thin-bedded, black limestone of bed *d*, and the 52 feet of thin-bedded, dark gray limestone of bed *e*, form a unit, inasmuch as they are all argillaceous limestones of which the analysis presented below is probably not an average one. More analytical work would probably show that this group of beds will supply the best cement rock of the region, so far as composition goes, the succeeding limestones proving upon analysis to be less favorable in composition. The high ratio between silica and iron-alumina shown in this analysis is probably exceptional.

Analysis of dark gray, argillaceous limestone, bed 3e, Chambersburg formation near Strasburg, Va.

(J. H. Gibboney, Analyst.)

	Per cent.
Insoluble	19.78
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	1.88
Lime (CaO)	41.60
Calcium carbonate ($CaCO_3$)	74.28
Magnesia (MgO)	0.39
Magnesium carbonate ($MgCO_3$)	0.82
Total	99.80

Beds 3f, 3g.—The 125 feet of strata composing these two beds are much alike in both their lithologic and chemical characteristics, and for that reason they are grouped together.

Analyses of dove limestones, beds 3f, 3g, Chambersburg formation, near Strasburg, Va.

(J. H. Gibboney, Analyst.)

	I.	II.
	Per cent.	Per cent.
Insoluble	12.10	8.68
Alumina (Al_2O_3), Iron oxide (Fe_2O_3)	1.48	1.32
Lime (CaO)	47.40	49.68
Calcium carbonate ($CaCO_3$)	84.64	88.71
Magnesia (MgO)	0.80	0.64
Magnesium carbonate ($MgCO_3$)	1.68	1.34
Total	99.90	100.05

I. Thin-bedded, dove limestone, bed 3f, Strasburg section.
II. Massive, dove limestone, bed 3g, Strasburg section.

Beds 3h, 3i.—These two beds have essentially the same chemical composition and resemble each other considerably in physical aspect. A sample supposed to be an average specimen gave the following analysis, which runs higher in lime than such a rock would indicate:

Analysis of gray, earthy limestone, bed 3i of Chambersburg formation, near Strasburg, Va.

(J. H. Gibboney, Analyst.)

	Per cent.
Insoluble	12.00
Alumina (Al_2O_3), Iron oxide (Fe_2O_3)	2.26
Lime (CaO)	47.16
Calcium carbonate ($CaCO_3$)	84.21
Magnesia (MgO)	0.54
Magnesium carbonate ($MgCO_3$)	1.18
Total	99.60

Bed 4.—The value of the calcareous shales at the base of the Martinsburg for mixture with pure limestone is evident from the following analysis:

Analysis of calcareous shales at base of Martinsburg shale, Strasburg, Va.

(J. H. Gibboney, Analyst.)

	Per cent.
Insoluble	27.60
Alumina (Al_2O_3), Iron oxide (Fe_2O_3)	3.36
Lime (CaO)	37.40
Calcium carbonate ($CaCO_3$)	66.97
Magnesia (MgO)	0.58
Magnesium carbonate ($MgCO_3$)	1.22
Total	99.15

Woodstock and vicinity.—Several hundred feet of argillaceous limestones of the Chambersburg formation may be found just east of Woodstock before the Martinsburg shale is encountered. These limestones and the overlying shales dip at an angle of about 40° southeast. Practically the same thickness of cement rock is exposed to the northeast and southwest of Woodstock, but although the outcrops are not as good as those noted in the Strasburg area, essentially the same section may be found. As this line of outcrops is paralleled by the Southern railroad, which is at no place more than two miles distant, favorable sites for cement plants are offered. The most promising location, however, is in the immediate vicinity of Woodstock, since here the cement rocks outcrop on the western side of the North Fork of the Shenandoah river. Farther south the river flows between the railroad and the cement outcrop, so the cost of a spur line would thus be greatly increased.

Pure limestones for mixture with the cement rock can be found in the immediate vicinity, west of the line of the outcrop of the argillaceous rock. Limestone strata high in calcium carbonate and low in magnesia were found interbedded with the dolomites west of Woodstock, and more extended search would no doubt reveal an ample supply. The following analyses are of the Stones River and argillaceous Chambersburg limestones in this vicinity:

Analyses of limestones, Woodstock, Va.

(J. H. Gibboney, Analyst.)

	I.	II.	III.
	Per cent.	Per cent.	Per cent.
Insoluble	6.26	14.88	10.04
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	4.82	2.38	1.46
Lime (CaO)	18.96	45.00	48.48
Calcium carbonate ($CaCO_3$)	33.88	80.36	86.57
Magnesia (MgO)	0.91	1.04	0.73
Magnesium carbonate ($MgCO_3$)	1.91	2.18	1.54
Total	96.87	99.80	99.61

I. Somewhat siliceous limestone, Stones River formation.
II. Argillaceous limestone, upper part of Chambersburg formation.
III. Dark blue limestone, lower part of Chambersburg formation.

Woodstock is situated upon the Stones River limestones, although exposures of these strata are few here. Just north of the town, however, outcrops occur in the fields, showing the usual thickness and lithologic

characters of this formation. The following section, embracing Chambersburg limestone only, occurs along the small creek and in the fields near the ice factory, just east of the town:

Geologic section just east of Woodstock, Va.

		Feet.
3.	Martinsburg shale	——
2.	Chambersburg limestone (upper division). Hard, calcareous shales and shaly black limestone. Seventy-five feet exposed but a thickness of two hundred feet at least occurs before the overlying shales are first met. Some of the layers crowded with *Echinosphærites*, *Christiania*, and other fossils of this formation. Analysis 2 of the table on page 82 is taken from a sample of this bed	75+
1.	Chambersburg limestone (lower division). Massive blue and gray limestone. A few of the layers are blue and crystalline, but the majority are dark blue, fine-grained strata weathering to a grayish color. The upper twenty feet is more argillaceous and upon weathering breaks up into small rounded fragments. About thirty feet of rock toward the middle portion of this division are filled with lighter colored material in streaks penetrating the rock in all directions. Upon exposure these weather out in marked relief. Fossils are uncommon, although a few gastropods occur in the lower part and *Solenopora* may be found sparingly in the middle and upper thirds. Analysis 3 of the table mentioned above is of a sample from the lower third of this division	150

The good railroad facilities of this vicinity, both for obtaining a fuel supply and for shipping the finished material, have been noted. Coal could be secured from the north via the Baltimore and Ohio and Southern railroads, and from the south via the Chesapeake and Ohio and the Southern railroads. By the same lines the finished material could be shipped to the east and tide-water.

Professor Rogers has published four analyses of rocks from the vicinity of Woodstock. The exact geological horizon of these samples is unknown, but the writer has attempted to place them.

Analyses of limestones, vicinity of Woodstock, Va.

	I.	II.	III.
	Per cent.	Per cent.	Per cent.
Calcium carbonate ($CaCO_3$)	14.00	15.83	12.63
Magnesium carbonate ($MgCO_3$)	10.10	11.34	10.12
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3) }	0.54	0.74	0.48
Silica (SiO_2)	4.85	1.41	1.52
Water	0.15	0.14	9.25
Loss	0.36	0.54	——
Total	30.00	30.00	34.00

I. Light gray coarse-grained limestone, probably from Beekmantown strata, halfway between Woodstock and Crabill's tavern.

II. Light blue compact magnesian Stones River limestone from vicinity of Woodstock.
III. Light bluish gray compact limestone, probably of Stones River age, west base of Little Fort mountain, opposite Woodstock.

The following analysis, also quoted by Professor Rogers, seems to have been made from the Eden or lower Massanutten sandstone:

Analysis of calcareous sandstone, Woodstock road leading into Big Fort Valley.

	Per cent.
Calcium carbonate ($CaCO_3$)	11.24
Magnesium carbonate ($MgCO_3$)	5.40
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	9.36
Silica (SiO_2)	73.20
Water	0.80
Total	100.00

Pughs Run, 2 miles north of Woodstock.—In the gorge cut by this stream down to the North Fork of the Shenandoah river an excellent section is exposed, where nearly every foot of strata from the Beekmantown dolomite to the Martinsburg shale may be studied. Here the more or less pure limestones at the top of the Stones River formation are being quarried for lime, but the succeeding argillaceous strata are recommended as a possible source of cement rock. This section follows:

Geologic section, Pughs Run, Va.

	Feet.
4. Martinsburg shale; dark brown and olive shales, mainly covered	—
3. Chambersburg limestone:	
(c) Massive dark blue to black, fine-grained homogeneous, argillaceous limestone	140+
(b) Thin-bedded clayey limestone and calcareous shales containing the characteristic fossil *Nidulites*. The limestone layers are blue, granular, and somewhat pure below but become more argillaceous, fine-grained, hard, and dark blue or black in upper part	200
(a) Massive blue crystalline, somewhat cherty. Many of the layers crowded with bifoliate bryozoa	20
2. Stones River limestone:	
Massive dolomitic and interbedded pure limestone of black, bluish gray, and dove color. The pure dove layers are most abundant at the top where they are being quarried by the Woodstock Lime Co.	600+
1. Knox dolomite	—

Mount Jackson and New Market.—Exposures of the argillaceous limestone may be seen in the foothills of Short mountain, several miles east of Mount Jackson, and also in the immediate vicinity of New Market. Practically the same thickness of rock determined at Woodstock and vicinity is shown here, while the analysis of the rocks at both of these places indicates that in chemical composition at least they are quite similar to good Lehigh rock.

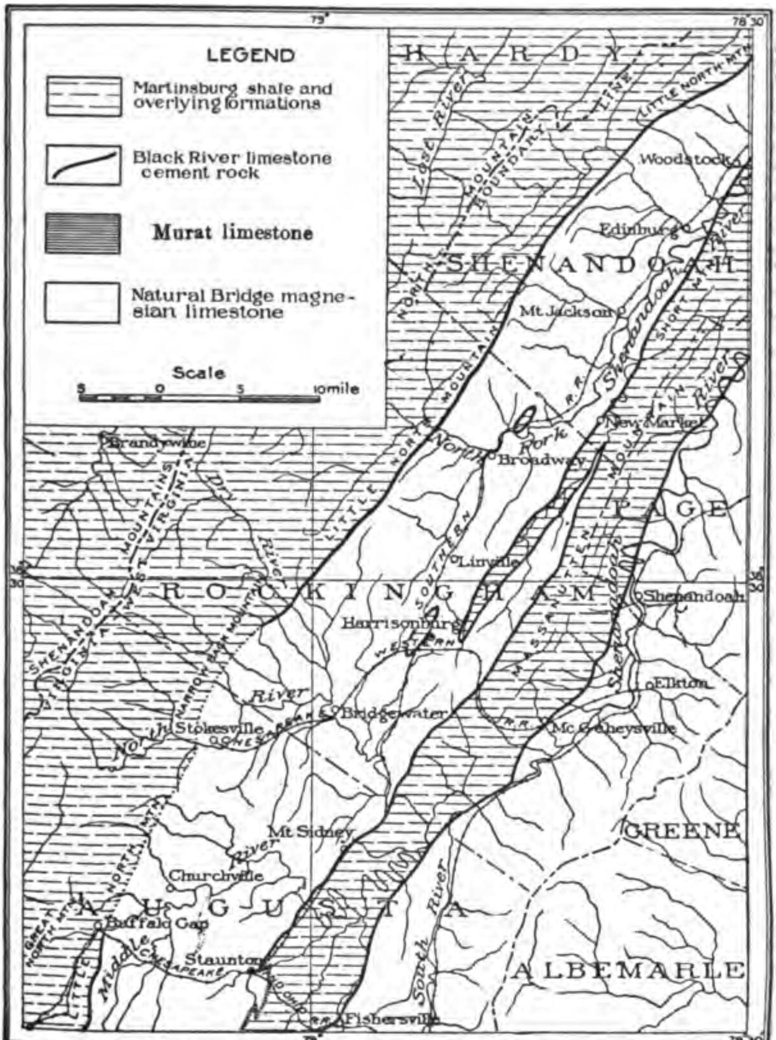


Fig. 9.—Map of the Valley of Virginia from Woodstock to Staunton. Unshaded area includes Natural Bridge limestone and underlying formations.

Analysis of argillaceous limestone near Mount Jackson, Va.

(J. H. Gibboney, Analyst.)

	Per cent.
Silica (SiO_2)	18.20
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	8.00
Calcium carbonate ($CaCO_3$)	70.00
Magnesium carbonate ($MgCO_3$)	2.00
Water (H_2O)	3.00
Total	101.20

The limestones in the vicinity of New Market were analyzed under the direction of Professor Rogers with a view to their use as a natural cement rock. The results from these samples, with the horizon as determined by the present writer, are as follows:

Analyses of limestones, vicinity of New Market, Va.

	I.	II.	III.
	Per cent.	Per cent.	Per cent.
Calcium carbonate ($CaCO_3$)	81.00	13.50	86.16
Magnesium carbonate ($MgCO_3$)	10.60	10.63	4.50
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	0.28	0.17	0.85
Silica (SiO_2)	7.60	0.60	
Water / Loss	0.52	0.10	6.50
Total	100.00	25.00	98.01

I. Grayish blue, fine-grained limestone, New Market, Va., probably from the Stones River formation.

II. Light bluish gray, moderately fine-grained limestone, 4 miles south of New Market, Va., probably from the magnesian beds of the Stones River formation.

III. Dun-colored limestone, making excellent lime, ½ mile west of New Market, Va. Stones River formation.

Analyses of other limestones of Shenandoah county were quoted by Professor Rogers as follows. The localities are too indefinite for an opinion as to their age:

Analyses of limestones, Shenandoah County, Virginia.

	I.	II.
	Per cent.	Per cent.
Calcium carbonate ($CaCO_3$)	49.00	75.96
Magnesium carbonate ($MgCO_3$)	38.80	9.12
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	0.84	0.92
Silica (SiO_2)	10.80	13.60
Water	0.56	0.40
Total	100.00	100.00

I. Bluish gray, compact limestone, Stage road, Shenandoah county.

II. Dark blue fine-grained limestone from same locality.

WARREN COUNTY.

The materials suitable for the manufacture of Portland cement in this county are limited to the western side of the narrow valley lying between the Blue Ridge and Massanutten mountains. These materials are the pure and argillaceous Ordovician limestones which may be found along a northeast-southwest course approximately following the middle of the Valley. On account of the meanderings of the South Fork of the Shenandoah river, the boundary line between the pure and dolomitic limestones is first on one and then on the other side of the stream. Because this line follows the river valley so closely, exposures of the cement rock are few, these strata in most places being buried beneath a considerable thickness of stream deposits. At Riverton and a few points to the north, however, the rocks are well exposed.

Riverton and vicinity.—Three distinct bands of cement rock outcrop are found at this place and in the immediate vicinity, on account of the development of a fold in the Ordovician rocks east of the Massanutten mountain syncline. As shown on the map, Riverton itself is built upon the Martinsburg shale which forms the highest beds of this more eastern syncline, but just to the east and to the west of the town the strata of the Chambersburg and Stones River formations may be seen. The latter formation is being extensively quarried at a locality just north of Riverton. The succession of rocks in the Riverton area differs slightly from the section seen at Strasburg to the west in the lithologic character of the strata. The rocks of the Stones River formation are massive, compact, black and blue, often argillaceous limestone, with a splintery fracture. As the following analysis shows, an average sample runs high in lime, but many of the layers will give a greater percentage of clayey material. Some of the strata will, however, undoubtedly run as high in lime as the corresponding rocks at Strasburg.

Analysis of black limestone, Stones River formation, Riverton, Va.

(J. H. Gibboney, Analyst.)

	Per cent.
Insoluble	3.11
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	0.64
Lime (CaO)	53.10
Calcium carbonate ($CaCO_3$)	94.82
Magnesia (MgO)	0.73
Magnesium carbonate ($MgCO_3$)	1.53
Total	100.10

The rocks of the Chambersburg formation here consist of well defined layers of black, compact, hard, argillaceous limestone, 1 to 6 or more inches in thickness, separated by thin bands of shale. These limestone layers, as shown by the analysis below, contain more calcium carbonate than required in the cement mixture, but it is very probable that experimentation will show that by mixing the interbedded shales with them the required composition will be attained.

Analysis of compact, black, argillaceous limestone, Chambersburg formation, Riverton, Va.

(J. H. Gibboney, Analyst.)

	Per cent.
Insoluble	15.88
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	0.92
Lime (CaO)	46.34
Calcium carbonate ($CaCO_3$)	82.75
Magnesia (MgO)	0.21
Magnesium carbonate ($MgCO_3$)	0.44
Total	99.99

PAGE COUNTY.

Practically the same conditions of cement rock occurrence as that just described for Warren county hold for Page county, the line of outcrop cutting across the various meanderings of the South Fork of the Shenandoah river and following approximately a northeast-southwest direction. In addition to the fact that the argillaceous and pure limestones are usually covered by recent deposits, the transportation facilities in Page county are some distance from this line. An argillaceous limestone outcropping on the extreme northern edge of Page county along the line mentioned gave the following very favorable composition:

Analysis of argillaceous (Chambersburg) limestone 5 miles east of Woodstock, Va.

(Wirt Tassin, Analyst.)

	Per cent.
Silica (SiO_2)	16.34
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	7.49
Calcium carbonate ($CaCO_3$)	74.14
Magnesium carbonate ($MgCO_3$)	1.00
Water (H_2O)	2.00
Total	100.97

The dolomitic limestones of Page county received considerable attention from Professor Rogers, as is evident from the following table of analyses quoted from the "Geology of the Virginias":

Analyses of dolomitic limestones, Page county, Virginia.

	I.	II.	III.	IV.
	Per cent.	Per cent.	Per cent.	Per cent.
Calcium carbonate ($CaCO_3$)	78.00	13.01	69.60	70.16
Magnesium carbonate ($MgCO_3$)	11.37	10.45	27.04	25.96
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3) }	5.50	0.30	0.40	1.60
Silica (SiO_2)	0.77	1.17	2.60	1.48
Water } Loss }	4.86	0.07	0.36	0.80
Total	100.50	25.00	100.00	100.00

	V.	VI.	VII.
	Per cent.	Per cent.	Per cent.
Calcium carbonate ($CaCO_3$)	60.92	47.48	13.40
Magnesium carbonate ($MgCO_3$)	36.48	45.80	9.78
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3) }	0.60	0.80	0.19
Silica (SiO_2)	1.44	5.40	1.47
Water	0.56	0.56	0.16
Total	100.00	100.04	25.00

I. Dingy blue limestone of firm texture, from vicinity of Luray, Virginia.
II. Light brown compact limestone, south side of Shenandoah river, 2 miles from Blackford's furnace.
III and IV. Blue limestone from Page county. Exact locality not given.
V. Bluish gray limestone from Page county. Exact locality not given.
VI. Crystalline gray limestone, spotted with white. Shenandoah river, Page county.
VII. Light blue, subcrystalline limestone from Dr. Blackford's mill race in Page county.

ROCKINGHAM COUNTY.

As this county embraces the full width of the Shenandoah Valley, it includes several distinct lines of outcrop of the Ordovician rocks. The easternmost of these is brought up on the east and west sides of the Massanutten mountain syncline, which, although the mountain itself extends only to the middle portion of the county, outcrops throughout Rockingham and counties still farther south. A somewhat flexuous northeast-southwest line passing just west of the towns of Shenandoah, Greenwood, McGaheysville,

Evanwood, and Weyer Cave, marks the course where the easternmost exposures may be expected to outcrop; while on the western side of the mountain a similar line just east of Paulington, Keezletown, and Weyer Cave station, indicates where these same strata come to the surface again. Just south of New Market in Shenandoah county, a second syncline, exposing the Martinsburg shale as the highest rocks, has its origin, and extends southwest to a point about the latitude of Harrisonburg. This syncline is never more than a few miles wide, and although the underlying pure limestones may be found at some localities, yet very often these strata are faulted out, and the shales rest against the dolomitic rock. Remnants of a third syncline running in the same northeast-southwest direction may be found in the middle portion of the Valley west of Harrisonburg, but only in one area are enough of the argillaceous rocks shown to make it of economic importance. This is in the immediate vicinity of Harrisonburg, particularly to the west of the town. The last outcrop of these limestones is on the western side of the Valley along the foothills of Little North mountain, and Narrow Back mountain. Along this area faulting is common, the dolomitic limestones often resting upon the Martinsburg shale or still higher formations, thus cutting out the strata of most economic importance.

The railroad facilities of Rockingham county are especially good when compared with other counties of the Valley. This fact, together with the good rock shown at many places, makes the county rich in cement resources.

Harrisonburg and vicinity.—A syncline showing the argillaceous limestones and Martinsburg shale occurs just west of Harrisonburg and extends northeast-southwest for a distance of some miles. The cement rock is especially well shown along the street just west of the Southern railroad depot, but exposures of the shales and underlying argillaceous rocks may be seen along the country roads going northwest, west, and southwest from the town. The thickness of the argillaceous limestones in this vicinity could not be ascertained with certainty because of the lack of continuous exposures, but it probably does not fall short of 200 feet. Fossils indicating the Chambersburg age of the strata were not uncommon in the rocks shown along the western edge of the town.

Purer limestone deposits are found in some quantity east and southeast of Harrisonburg. Exposures of this rock may be seen in a cut on the Chesapeake and Western railroad just east of the crossing with the Southern railroad. Here is found a rather pure gray limestone having the composition shown in analysis No. 1 of the table below.

From 75 to 100 feet of argillaceous limestones and calcareous slates are exposed in a cut on the Chesapeake and Western railroad southwest of Harrisonburg and just west of the Southern crossing. Samples from this cut were analyzed by Mr. Charles Catlett, with the result shown in analysis II.

About 1½ miles north of Harrisonburg the Southern railroad passes through a cut about 20 feet high and 400 to 600 feet in length, exposing comparatively horizontal slaty limestone. This was found to have the composition shown in analysis IV.

Partial analyses of cement materials in the vicinity of Harrisonburg, Va.
(Charles Catlett, Analyst.)

	I.	II.	III.	IV.
	Per cent.	Per cent.	Per cent.	Per cent.
Lime (CaO)	54.24	35.79	49.00	38.32
Magnesia (MgO)	0.60	1.42	2.36	1.67
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3) }	0.60	3.32	0.70	1.58
Insoluble	2.08	27.06	7.00	25.24

I. Pure gray limestone, cut on Chesapeake and Western railroad just east of crossing with the Southern railroad.
II. Calcareous slates, exposed in cut on Chesapeake and Western railroad just west of crossing with the Southern railroad.
III. Dark, friable limestones, exposed at crossing of railroads just south of Harrisonburg.
IV. Calcareous slates, cut along Southern railroad 1½ miles north of Harrisonburg.

The various exposures in the vicinity of Harrisonburg indicate that the general sequence of the rocks is as follows:

Geologic section, Harrisonburg, Va.

		Feet.
5.	Typical Martinsburg shale, argillaceous above but more calcareous toward the base	100
4.	Calcareous shales, semicrystalline and argillaceous limestone containing the fauna of the *Christiania* bed in the Strasburg section	50
3.	Massive dark blue compact limestone with splintery fracture. Numerous fossils in the upper layers, *Nidulites* being the predominating form	100
2.	Dove, dark blue, and sometimes black, rather pure limestone, alternating with magnesian layers. Gastropoda of Stones River types only fossils observed	200
1.	Typical Beekmantown limestone weathering into chert	——

In this section bed 2 represents the Stones River formation, while beds 3 and 4 are the equivalent of the Chambersburg formation. Although the thickness given in each case should be considered a minimum, the fact is to be noted that both the Stones River and Chambersburg formations have thinned considerably going south.

The following analyses were made of samples collected from the various beds as indicated. The rocks of bed 1 run high in magnesia as usual and therefore no samples were analyzed quantitatively.

Analyses of limestones of Stones River formation. Bed 2 of Harrisonburg, Va., section.

(J. H. Gibboney, Analyst.)

	I.	II.	III.
	Per cent.	Per cent.	Per cent.
Insoluble	9.10	9.60	8.66
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3) }	1.32	2.30	1.40
Lime (CaO)	48.62	49.12	48.68
Calcium carbonate ($CaCO_3$)	86.82	87.71	86.93
Magnesia (MgO)	1.29	0.22	0.75
Magnesium carbonate ($MgCO_3$)	2.71	0.46	1.58
Total	99.95	100.07	98.57

I. Compact black limestone, east of Harrisonburg, Virginia.
II. Black crystalline limestone, along Chesapeake and Western railroad, southeast of Harrisonburg.
III. Compact black limestone, just northeast of Harrisonburg.

The foregoing analyses are, as the percentages show, of rock well fitted for the burning of lime or for admixture with more shaly cement materials.

Analyses of dark blue, compact limestones of Chambersburg formation. Bed 3 of Harrisonburg, Va., section.

(J. H. Gibboney, Analyst.)

	I.	II.
	Per cent.	Per cent.
Insoluble	4.60	8.68
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3) }	0.56	0.94
Lime (CaO)	51.52	50.60
Calcium carbonate ($CaCO_3$)	92.00	90.36
Magnesia (MgO)	1.33	0.20
Magnesium carbonate ($MgCO_3$)	2.79	0.41
Total	99.95	100.39

The analyses just given are of samples collected from the strata outcropping along the railroad track near the Southern railroad depot at Harrisonburg. As the figures indicate, this rock is very similar in composition to the underlying pure limestone of bed 2.

Analyses of limestone of Chambersburg formation. Bed 4 of Harrisonburg, Va., section.

(J. H. Gibboney, Analyst.)

	I.	II.	III.
	Per cent.	Per cent.	Per cent.
Insoluble	30.72	12.82	23.24
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3) }	3.52	1.84	3.22
Lime (CaO)	35.16	45.40	39.80
Calcium carbonate ($CaCO_3$)	62.78	81.07	71.07
Magnesia (MgO)	0.34	1.20	0.82
Magnesium carbonate ($MgCO_3$)	0.71	2.52	1.72
Total	97.73	98.25	99.25

I and II. Semicrystalline limestone, western edge of Harrisonburg.
III. Argillaceous limestone, Harrisonburg, just west of Southern railroad station.

Specimens 1 and 2 were collected with a view to show the extremes in variation of the composition of this semicrystalline limestone which is quite abundant in this region. Specimen 3 was an average sample of the ordinary argillaceous rock. The following analysis is of calcareous shales collected along the street west of Southern railway depot.

Analysis of Martinsburg shale. Bed 5 of Harrisonburg, Va., section.

(J. H. Gibboney, Analyst.)

	Per cent.
Insoluble	30.56
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3) }	3.82
Lime (CaO)	34.20
Calcium carbonate ($CaCO_3$)	61.07
Magnesia (MgO)	1.64
Magnesium carbonate ($MgCO_3$)	3.44
Total	98.89

The composition of these calcareous shales well illustrates the use to which the lower part of the Martinsburg shale can be put. Although the amount of lime in this particular sample is higher than usual, still, with a slight addition of pure limestone, a good cement mixture may be obtained.

Massanutten mountain syncline.—Along the eastern edge of this syncline in Rockingham county the argillaceous limestones are seldom seen. Whether this is due to a lack of deposition or to overthrust faulting of the lower limestones upon the shales was not determined, although the latter is probably the case. The usual sequence of Ordovician rocks may be seen

along the western edge of the syncline, but as the analysis given below indicates, the argillaceous limestones are here unusually high in silica and low in lime.

Analysis of Chambersburg limestone, 3 miles west of Montevideo, Va.

(J. H. Gibboney, Analyst.)

	Per cent.
Insoluble	37.06
Alumina (Al_2O_3), Iron oxide (Fe_2O_3)	2.60
Lime (CaO)	32.18
Calcium carbonate ($CaCO_3$)	57.46
Magnesia (MgO)	0.70
Magnesium carbonate ($MgCO_3$)	1.47
Total	98.59

Western edge of Valley.—The outcrops of the middle Ordovician limestones along the western edge of this part of the Valley are in general so remote from railroads that, in spite of the excellent rock shown at a few places, exploitation of this region is at present useless. Furthermore, throughout a considerable portion of this region the argillaceous limestones are cut out by overthrust faulting, the magnesian limestone resting upon the shales or still higher formations. But a single area can be mentioned in which the cement rocks are exposed within a reasonable distance of a railroad. Several miles north of Stokesville, the terminus of the Chesapeake and Western railroad, and a few miles south of Little North mountain, good outcrops of the rock are encountered. The quantity and quality of these limestones are such that, with the railroad facilities so near at hand, the rock will undoubtedly prove of economic importance. Shales are at hand for mixing with the cement rock when its percentage of lime is too high, while pure limestones, to increase the percentage when necessary, are found in sufficient quantity in the Valley just to the east. Indeed, even with the present facilities, this is a promising locality.

The composition of an excellent cement rock from this region is shown by the following analysis:

Analysis of black limestone from an exposure several miles north of Stokesville, Va.

(Wirt Tassin, Analyst.)

	Per cent.
Silica (SiO_2)	14.34
Alumina (Al_2O_3), Iron oxide (Fe_2O_3)	6.49
Calcium carbonate ($CaCO_3$)	73.14
Magnesium carbonate ($MgCO_3$)	2.90
Water (H_2O)	4.00
Total	100.87

Analyses of the magnesian limestones from the western side of the Valley have been published by Professor Rogers. These are quoted below:

Analyses of magnesian limestones, southern part of Rockingham county, Virginia.

	I.	II.
	Per cent.	Per cent.
Calcium carbonate ($CaCO_3$)	15.52	13.50
Magnesium carbonate ($MgCO_3$)	12.83	10.56
Silica (SiO_2)	0.58	0.39
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	0.25	0.38
Water	0.12	0.17
Loss	0.70	——
Total	30.00	25.00

I. Compact dull gray limestone from the Trap Dyke, 8½ miles west of Mount Crawford, Virginia.
II. Light gray subcrystalline limestone from same locality.

Mt. Horeb Church.—A fairly complete section of the Ordovician limestones is presented in this vicinity, while the following succession of strata was observed along the Rawley Springs pike, about nine miles northwest of Harrisonburg.

Geologic section, Mt. Horeb Church, Va.

		Feet.
6.	Fine-grained shales with few if any limestone bands	200+
5.	Thin-bedded black compact limestone with thin shale bands	300
4.	Dark blue compact massive limestone much fractured and seamed with calcite	150
3.	Thin-bedded blue limestone with some shale at the top, merging below into knotty, argillaceous limestone	300
2.	Dark blue splintery limestone, cherty at the top, thickness not measured because of lack of exposures	——
1.	Typical cherty dolomite of Beekmantown formation	——

The section along the western edge of the Valley in this portion of Virginia differs from those exposed further east in that a greater thickness of pure and argillaceous limestones is developed between the top of the dolomitic Beekmantown formation and the more shaly portion of the Martinsburg shale. This greater development of limestones is due in part to an increased thickness of the Chambersburg formation, but mainly to the fact that here the Trenton phase of the Martinsburg shales consists of thin-bedded, pure limestone and calcareous shales instead of shale as elsewhere. In view of the thickness and the favorable chemical composition of this belt of limestone as shown by the following analysis, it is unfortunate that transportation facilities are not nearer at hand. However, in spite of the

present unfavorable outlook of this immediate region, samples of the various beds were taken for analysis, since this is a typical section of the Ordovician rocks along the western edge of the Valley in Rockingham, Shenandoah, and Frederick counties.

Bed 1.—Exposures of this bed are rather few, but areas underlain by this formation are readily recognized by the chert fragments in the soil. As elsewhere the limestones of the Beekmantown formation are dolomitic and therefore of no value as a Portland cement rock.

Bed 2.—Following these dolomitic strata are several hundred feet of dark blue, more or less pure limestone with a splintery fracture. On account of the lack of exposures and difficulty in determining the basal layers, the exact thickness of this division was not determined. A few fossils were observed and these—mostly gastropods—indicated the equivalence of these rocks with the Stones River formation as shown elsewhere in northwestern Virginia. Some of the strata of this division, especially those near the top, contain considerable chert, but as a rule the limestone is quite pure. The usual percentage of lime is indicated in the following analysis:

Analysis of dark blue, splintery limestone of Stones River age, bed 2 of Mt. Horeb Church section.

(J. H. Gibboney, Analyst.)

	Per cent.
Insoluble	8.06
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	1.14
Lime (CaO)	49.10
Calcium carbonate ($CaCO_3$)	87.68
Magnesia (MgO)	0.86
Magnesium carbonate ($MgCO_3$)	1.81
Total	98.69

Beds 3 and 4.—Together these beds comprise about 450 feet of rather pure blue and argillaceous limestone with some shale bands. Fossils are rather few in these strata, but the presence of *Echinosphærites*, especially, indicates the Chambersburg age of the rocks. Here this formation commences with about 150 feet of knotty, argillaceous limestone, average samples of which have a composition shown in analysis I of the following table. As the analysis indicates, the rock is higher in lime and lower in clayey material than required for typical cement rock.

This argillaceous limestone is succeeded by 150 feet of thin-bedded blue limestone with some shale in the upper part. Although quite different lithologically, this rock is very similar in chemical composition to the preceding, as analysis II shows.

Bed 4 consists of compact, massive limestone, dark blue in color and much fractured and seamed with calcite. Although it has a higher percentage of lime than the two divisions of bed 3, the value of the rock is less on account of the higher magnesian content. As indicated in the section, this division is not less than 150 feet in thickness.

Analyses of limestones of Chambersburg formation, beds 3 and 4 of Mt. Horeb Church section.

(J. H. Gibboney, Analyst.)

	I.	II.	III.
	Per cent.	Per cent.	Per cent.
Insoluble	14.68	15.32	4.04
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3) }	1.88	1.34	1.80
Lime (CaO)	45.76	46.12	44.84
Calcium carbonate ($CaCO_3$)	81.71	82.35	85.40
Magnesia (MgO)	0.02	0.10	3.96
Magnesium carbonate ($MgCO_3$)	0.05	0.21	8.36
Total	98.32	99.22	99.56

I. Knotty argillaceous limestone, lower part of bed 3.
II. Thin-bedded, blue limestone, near top of bed 3.
III. Dark blue, compact limestone, bed 4.

Bed 5.—Three hundred feet of limestone succeed the argillaceous and blue limestones of Chambersburg age in this section. As indicated elsewhere, such development of limestone is unusual, this horizon usually being occupied by more or less calcareous shale. This limestone is black, compact, and occurs in thin courses with thin shale bands intervening. Fossils are usually abundant, the surface of the limestone layer often being covered with characteristic Trenton species. Analyses of the limestone and the intervening shale bands are cited below:

Analyses of Trenton limestone and shale, bed 5 of Mt. Horeb Church section.

(J. H. Gibboney, Analyst.)

	I.	II.
	Per cent.	Per cent.
Insoluble	27.44	7.80
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3) }	4.06	0.90
Lime (CaO)	36.90	50.76
Calcium carbonate ($CaCO_3$)	65.89	90.64
Magnesia (MgO)	0.07	0.48
Magnesium carbonate ($MgCO_3$)	0.15	1.04
Total	97.54	100.38

I. Shale bands between limestones.
II. Thin-bedded, compact limestone.

Bed 6.—Although there is no sharp break between this and the preceding bed, the extremely few limestone bands and the more argillaceous character of the shales will distinguish the strata of bed 6. Fossils, particularly graptolites and trilobites, are somewhat abundant and show that these rocks are the equivalent of the Utica of the general time scale. The lower strata of bed 6 are fine-grained shales which, under the proper conditions, afford a fair slate. A small amount of slate for local use has been quarried from this horizon at several points in this portion of the Valley. The analysis of these fine-grained shales is as follows:

Analysis of Martinsburg shale (Utica horizon), bed 6, Mt. Horeb Church section.

(J. H. Gibboney, Analyst.)

	Per cent.
Insoluble	43.94
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	5.18
Lime (CaO)	26.28
Calcium carbonate ($CaCO_3$)	46.93
Magnesia (MgO)	0.03
Magnesium carbonate ($MgCO_3$)	0.07
Total	96.12

CAMBRIAN AND ORDOVICIAN STRATA OF CENTRAL WESTERN VIRGINIA.

According to the three divisions of western Virginia outlined on a previous page, central western Virginia extends from the Blue Ridge on the east to the state line on the west, is bounded on the north by Rockingham county, and on the south by Montgomery and Giles counties. It thus embraces the eight counties, Highland, Augusta, Bath, Rockbridge, Alleghany, Botetourt, Craig, and Roanoke. More or less abundant cement materials are found in each of these counties, but on account of better railroad facilities and more extended outcrops of Ordovician limestone, Augusta and Rockbridge counties deserve most attention.

PRINCIPAL GEOLOGIC FEATURES.

The general geology of this division, although somewhat similar to that of northwestern Virginia, begins to assume the complexity of the area farther south. As indicated on figure 18, the great faults of southwestern Virginia are found in its southern part, while the Massanutten mountain syncline and the structure along the western edge of the

Fig. 1.—Balcony Rock composed of Lower Cambrian quartzite. Corner of Rockbridge and Amherst counties, Balcony Falls.

Fig. 2.—Cliff of Sherwood dolomite, near Sherwood. Natural Bridge station on N. & W. and C. & O. railroads.

Valley in the northwestern part of the state may be traced through the northern part of the division. In the intermediate zone, namely in Rockbridge county, the Ordovician limestones are so situated as a result of folding, faulting, and erosion, that a considerable area is underlaid by them.

The principal features concerned in the exposure of the Ordovician limestones are as follows: The Massanutten mountain syncline enters the district from Rockingham county and occupies a portion of Augusta county, thus bringing the Ordovician limestones and shales to the surface as far south as Greenville. The faulting along the western edge of the Valley becomes less and less in Augusta county until the structure is practically normal. The cement limestones therefore are more abundant in this part of the Valley than northward along the same line. In the vicinity of Lexington the argillaceous limestones are found over a considerable area, and on account of close folding give the appearance of great thickness.

South of Rockbridge county the principal Ordovician outcrops follow the bases of the mountains and are thus exposed usually at some distance from railroads. Moreover, on account of the unusually steep dip of the strata, the outcrops are in long, narrow areas.

The regions of outcrop thus far noted are in the Appalachian Valley proper. West of this, namely in Alleghany, Bath, and Highland counties, anticlines are found, exposing these shales and limestones as their lowest strata. With the exception of the vicinity of Hot Springs, these anticline areas have no railroad facilities.

STRATIGRAPHY.

The sedimentary rocks of central western Virginia include strata ranging from the Cambrian to the Coal Measures, but as the present section is concerned mainly with the Cambrian and Ordovician rocks, the formations of these two periods only are described. The characteristics of the post-Ordovician formations of this region are noted in the generalized section on page 43, figure 2. Descriptions and analyses of the cement rocks in these later strata are given on subsequent pages.

As in other parts of western Virginia, four distinct phases of sedimentation are found in the Cambrian and Ordovician sections. These are in ascending order, (1) the arenaceous Lower Cambrian strata, (2) the dolomitic, pure, and argillaceous limestones of Cambrian and Ordovician age, (3) the Martinsburg shale, and (4) the Massanutten sandstone.

LOWER CAMBRIAN SEDIMENTS.

The various formations of Lower Cambrian age exposed along the west side of the Blue Ridge in central western Virginia have not been distinguished by separate names as in the region to the north. However, in a general way these formations are quite similar to the corresponding strata of northwestern Virginia, so that in all probability the use of the same formational names can be extended, at least in part, to the areas farther south. Professor Rogers, in his "Geology of the Virginias," has given the following description of these strata:

"The rock, or group of rocks, which is frequently exhibited in extensive exposures along the western side and base of the Blue Ridge, more especially in the middle counties of the Valley, is usually a compact, rather fine-grained, white or yellowish gray sandstone, where, resting on the declivity of the ridge, it presents a gentle inclination to the northwest—while the subjacent and more ancient strata of the ridge, in almost every instance, dip steeply to the southeast. In Page, Rockingham, Augusta, and Rockbridge counties this group forms the irregular and broken range of hills lying immediately at the foot of the main Blue Ridge, and sometimes attaining an altitude little inferior to that of the main mountain. A level region, sometimes of considerable breadth, and strewed profusely with fragments of this rock, in general intervenes between the rugged hills and the first exposures of the Valley limestones. . . . In many instances two, sometimes three, ranges of hills are interposed between the limestones and what may be considered the termination of the rocks of the Blue Ridge."

Of the more siliceous beds of these sandstones he says:

"In nearly all the exposures from Balcony Falls to Thornton's Gap, as well as at various other places, it exhibits vague fucoidal and zoöphytic impressions on the surfaces of bedding, together with innumerable markings at right-angles to the stratification, penetrating in straight lines to great depths in the rock, and from their frequency and parallelism determining its cleavage in nearly vertical planes. These markings are of a flattened cylindrical form, from ⅛th to 1-10th of an inch broad, giving the surface of the fractured rock a ribbed appearance, and resembling perforations made in sand which have been subsequently filled up, without destroying the distinctness of the original impressions." (pp. 167, 168.)

" . . . At Balcony Falls, where the western dips are preserved throughout a large part of the thickness of this formation, the most

Natural Bridge, Virginia. View from southeast side. Type exposure of Natural Bridge limestone. (Photo by C. D. Walcott.)

NATURAL BRIDGE, VIRGINIA.

favorable opportunities are presented for studying the composition and marking the arrangement of these rocks. The formation here rests upon igneous rocks, chiefly of the syenitic character, which in this place form the main axis of the Blue Ridge. These are well seen in traveling along the tow path of the canal which follows the course of the river through the wild and beautiful gorge by which it makes its way from the Valley eastward. As we approach the western terminus of the pass, we mark the commencement of the rocks of formation I, which are seen on the side of the canal lying on the syenitic mass with a northwest dip. The lowest stratum, or that in contact with the syenite, is a brownish decomposing slate, evidently much altered by its proximity to the igneous rock beneath; next is grayish and reddish sandstone; then a slate similar to the former, then a repetition of the sandstone, again a slate, and at the termination of the gap heavy beds of massive white sandstone, such as constitute the type of this formation. The average dip of the latter, as presented in the imposing cliffs which guard the entrance to the pass, is 55° N. W." (p. 205.)

SHENANDOAH GROUP.

The great limestone group succeeding the arenaceous Lower Cambrian deposits has been mapped in central western Virginia as in northwestern Virginia under the general name of the Shenandoah limestone. In the discussion of this limestone in the description of the region to the north, Professor Campbell's subdivisions were noted. These are, (1) Cambrian and Lower Ordovician (Sherwood, Buena Vista, and Natural Bridge), and (2) Middle Ordovician (Murat and Liberty Hall), and as central western Virginia is their type locality of outcrop the formations are again discussed.

Shady (Sherwood) limestone.—The basal 1,600 to 1,800 feet of the Shenandoah series are distinguished by Professor Campbell under the name of the Sherwood limestone on account of their occurrence in the bluff of the James river at Sherwood, Va. In this vicinity the lower part of the Sherwood limestone consists of white crystalline dolomite. This is followed by heavily bedded light blue and gray magnesian limestone with occasionally beds of argillaceous limestone and shale. It is in the latter occurrence that the formation may prove of some value, these argillaceous limestones and shales having a composition which will allow their use, particularly in the manufacture of natural cement. In northwestern Virginia the place of the Sherwood limestone is occupied by very similar strata

correlated with the Tomstown limestone of southern Pennsylvania. The principal outcrops of these formations are to be found along a rather narrow strip in the eastern part of the Valley just west of the Cambrian quartzite and shales previously described. The latter formations are sometimes found overthrust upon the Sherwood limestone, so that the younger rocks seem to conformably underlie the other. In place of the term Sherwood limestone, the U. S. Geological Survey has requested the use of the earlier name, Shady limestone, for this formation.

Wautaga (Buena Vista) shale.—The red shales underlying the great magnesian limestone formation of the Valley, and outcropping along a comparatively narrow strip just west of the Blue Ridge foothills, have been described by Professor Campbell as the Buena Vista shale. This name, however, has been preoccupied for a subdivision of Ohio Mississippian rocks, as pointed out by Professor Prosser[a], and another term becomes necessary. Two names appear available; first, the Wautaga formation proposed by Mr. Arthur Keith[b] for red and green shales occupying the same stratigraphic position in Tennessee and North Carolina, and second, the Waynesboro formation of southern Pennsylvania, mentioned in the discussion of northwestern Virginia. All three names probably apply to the same interval, and it is thought best to regard them as synonymous. According to Mr. Arthur Keith the Wautaga shale has been traced northward far enough to warrant the application of this name, instead of a new term to the preoccupied Buena Vista. This course, as well as the recognition of the same formation in northwestern Virginia, must be considered provisional, although it is believed to be in keeping with the facts.

In the vicinity of Buena Vista, Va., 600 to 900 feet of reddish shales with green, yellow, and brown bands, follow the Shady limestone. Mottled blue limestones alternate with the shale bands, especially in the lower part.

In northwestern Virginia this shale is usually of a reddish purple color and contains very little calcareous material. Good exposures are found along Antietam creek in Maryland.

The geologic age of this shale is still uncertain. Dr. Walcott found a trilobite closely related to Middle Cambrian species, at the base of this shale in central western Virginia, but more recently Prof. S. L. Powell, of Roanoke College, Salem, Va., has discovered fragments of Olenellus in the same strata of that vicinity. The Lower Cambrian age of the shale therefore seems most probable.

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[a]Amer. Journ. Sci. (4), XXI, 1906, p. 181.
[b]Cranberry folio (No. 90) U. S. Geological Survey.

Fig. 1.—View of the upper part of the Natural Bridge limestone, showing weathering into bands of chert nodules, 6 miles west of Lexington, Rockbridge county.

Fig. 2.—Same as Fig. 1.

NATURAL BRIDGE LIMESTONE, VIRGINIA.

The economic importance of the Wautaga shale lies mainly in the occurrence of limestones with the shales, especially in the lower part. These limestones have been found to be of such composition as to allow their use in the manufacture of natural cement. The rocks used by the natural cement plant near Balcony Falls, Va., are from this formation. Analyses of this rock are given for comparison with limestones of similar age in northwestern Virginia:

Analyses of limestone in Wautaga (Buena Vista) shale, near Balcony Falls, Va.

	I.	II.
	Per cent.	Per cent.
Silica (SiO_2)	17.21	17.38
Alumina (Al_2O_3)	Trace	7.80
Iron oxide (Fe_2O_3)	1.62	
Lime (CaO)	24.85	34.23
Magnesia (MgO)	16.58	9.51
Carbon dioxide (CO_2)	37.95	30.40

I. C. L. Allen, analyst. The Virginias, Vol. 3, p. 88.
II. E. C. Boynton, analyst. Gillmore: Limes, Cements, and Mortars, p. 125.

Natural Bridge limestone.—The heavy-bedded gray and light blue limestones distinguished by Professor Campbell under this name compose the most persistent formation of the Appalachian Valley. The chert fragments left in the soil after the disintegration of these dolomitic limestones are especially characteristic and serve to indicate the areas occupied by the formation particularly when outcrops are lacking. This chert is most abundant at several horizons in the upper beds, which for this reason commonly give rise to the ridges of the Valley in central western Virginia. The chert, however, although still quite a conspicuous feature of the formation, is less abundant in both northwestern and central western Virginia than in the region to the south.

Professor Campbell describes the formation as follows:

"This formation consists principally of heavy-bedded gray and light blue magnesian limestones with thin siliceous laminæ as a conspicuous feature, especially upon weathered surfaces. Beds of white and pinkish dolomite occur now and then. Calcareous sandstone strata from a few inches to eight feet thick are occasionally prominent. Black chert occurs in nodules more or less through the formation, but heavy beds of chert are usually very conspicuous near the top. Specimens of *Lingulepis* and *Obolus* were discovered by C. D. Walcott in this formation two miles below Buffalo

Mills on Buffalo creek in June, 1898, thus establishing by fossils the age of part of this limestone as Cambrian. Fossils from 300 or 400 feet below the top of this formation make the age of its upper beds Beekmantown ("Calciferous").

"On account of the difficulty of determining the geologic structure in this section the total thickness of the formation has not been accurately determined, but measurements which were made in a continuous series where there was no indication of folding or faulting indicate a thickness of over 3,500 feet. The Natural Bridge and its cañon display part of this limestone, and hence the name."

Professor Rogers (page 234 of "Geology of the Virginias") gives the following analyses of samples of blackish blue, compact limestone from the Natural Bridge formation at the type locality:

Analyses of Natural Bridge limestone, Natural Bridge, Va.

	I.	II.
	Per cent.	Per cent.
Calcium carbonate ($CaCO_3$)	15.97	20.81
Magnesium carbonate ($MgCO_3$)	12.30	4.18
Silica (SiO_2)	0.86	3.81
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3) }	0.24	0.66
Water	0.13	0.15
Loss	0.50	0.39
Total	30.00	30.00

Although the above analyses are believed to be typical of the Natural Bridge limestone, still some of the beds are known to contain a larger amount of calcium carbonate. A sample from the rather thin-bedded upper or Beekmantown portion, collected by the writer, was found to be much purer.

Analysis of Natural Bridge limestone (Beekmantown horizon), South River Station, Rockbridge county, Virginia.

(Wm. M. Thornton, Jr., Analyst.)

	Per cent.
Silica (SiO_2)	5.98
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3) }	1.01
Magnesia (MgO)	1.39
Lime (CaO)	50.48
Magnesium carbonate ($MgCO_3$)	2.69
Calcium carbonate ($CaCO_3$)	90.14
Total	99.82

Fig. 1.—Weathered surface of dolomitic limestone from the Beekmantown horizon of the Natural Bridge limestone, near South River station, Rockbridge county, Va. These limestones are solid and massive when freshly exposed, but weathering brings out the laminated structure seen in the photograph.

Fig. 2.—Characteristic exposures of the Liberty Hall limestone in the railroad cu at Lexington, Va. The thin-bedded but solid nature of the strata is shown.

The lamination which Professor Campbell mentions is most abundant in the upper beds and is illustrated on plate XIII. As a source of materials for the manufacture of Portland cement, the Natural Bridge limestone cannot be considered of any importance.

MIDDLE ORDOVICIAN STRATA.

The heavy cherty beds of the Natural Bridge formation are usually followed by a massive gray, coarsely crystalline pure limestone, to which Professor Campbell has applied the name Murat from its occurrence along Buffalo creek at Murat post-office, Va. This marble-like limestone is succeeded by argillaceous strata possibly 1,000 feet in thickness, making up the Liberty Hall formation. Between the Natural Bridge and the Murat are occasionally pure dove and laminated, mottled limestones which, although noted by Professor Campbell in the field, were not considered by him of sufficient importance to warrant a name. These strata are certainly not developed sufficiently to be mapped as a separate unit, but they represent the Stones River formation of other parts of Virginia and therefore are of interest in the discussion of the stratigraphic record. The most complete Middle Ordovician section observed in central western Virginia was at the type locality of the Murat limestone. The succession here is as follows:

Geologic section, Murat Post-Office, Rockbridge county, Virginia.

	Feet.
Liberty Hall limestone:	
Fine-grained, dark argillaceous limestone, thin-bedded above, more massive below	1,000±
Murat limestone:	
Massive, coarsely crystalline, gray limestone with *Solenopora compacta*, bryozoa and other fossils	125
Stones River formation:	
Massive, dark blue, comparatively pure subcrystalline limestone with a few magnesian layers	20
Laminated blue to drab mottled limestone	14
Thin-bedded dark blue magnesian limestone with thin beds of solid, black, slaty chert	9
Massive dove limestone showing gastropods on weathered surfaces	6
Natural Bridge (Beekmantown):	
Rather massive magnesian limestone weathering into laminated strata bearing porous sandy chert	——

Of the different divisions distinguished in the section, the Liberty Hall and Murat are the only formations worthy of consideration as a source of cement materials, the former as a cement rock itself, and the latter as a more or less pure limestone which could be used in mixture.

The general features of the geologic section at Lexington have been pointed out by Professor Campbell, but the following more detailed section is offered to show the variation in the several divisions, and especially to point out the subdivisions recognized in the Liberty Hall formation:

Geologic section, Lexington, Va., and vicinity.	Feet.
III. Lowville and Black River limestones, including Liberty Hall and Murat formations.	
2. Liberty Hall formation:	
(d) More or less thin-bedded argillaceous limestone and calcareous shales	500±
(c) Fine-grained, dark, massive argillaceous limestone with an obscure conchoidal fracture	250±
(b) Argillaceous knotty limestone with many fossils, brachiopods and trilobites particularly numerous. *Ampyx* and *Agnostus* characteristic fossils	40
(a) Crystalline and subcrystalline limestone full of bryozoa, sponges, etc. Often absent from sections	10
1. Murat formation:	
Massive gray crystalline limestone weathering into a red, clayey soil comparatively free from chert	100
II. Stones River limestone.	
(b) Massive, somewhat cherty mottled blue limestone, seldom shown and of slight thickness. Fossils numerous	——
(a) Massive dove limestone. Seldom present in the section and thickness slight when present	——
I. Natural Bridge limestone.	
Gray and light blue magnesian limestone weathering into chert. Conspicuous beds of chert near the top	——

Stones River formation.—In central western Virginia the strata of Stones River age are so seldom shown that in former publications they have been considered as practically absent. A few areas show a slight development, but as a source of cement material, the formation may be neglected. As indicated in the preceding sections, two rather well marked members may be distinguished—a lower of purer, homogeneous, massive dove limestone and an upper of more shaly, mottled blue limestone. Both divisions are better developed in the eastern portion of the Great Valley in southwestern Virginia. Faunally and lithologically these strata are identical in both areas. The lower dove limestone lithologically is a typical development of the Stones River formation, but the upper blue laminated and mottled beds greatly resemble the Chazy of New York not only in the character of the rock but in its included fossils as well.

The argillaceous, rather thin-bedded, mottled blue limestone holding Chazy fossils underlies the Athens shale in Tennessee, and was given the name of Lenoir limestone by Safford and Killebrew,[a] from its occurrence

[a]Elements of the Geology of Tennessee, 1900, p. 120.

at Lenoir's Station, Tenn. The formation at the type locality does not include the underlying dove limestone of Stones River age, but was applied distinctly to the stratum of blue shaly limestone holding *Maclurea magna.* This large gastropod often occurs in the "Lenoir limestone" in such numbers that Professor Safford, in his "Geology of Tennessee," described the strata as the Maclurea limestone. In Virginia, this fossil is not so abundant, although cross sections of the shell may be found in rock of almost every exposure. The brachiopod, *Camarotoechia plena,* likewise abundant in Tennessee, is rare in Virginia, but the coral *Stylarea parva* is equally common in both states. At some localities in Tennessee Professor Safford included the lower dove limestones in his Lenoir formations. The division of the Chazy represented by these upper mottled blue limestones is of Stones River age, and it therefore seems best to apply this earlier name to the formation as a whole.

The chemical composition of the several divisions of this Stones River limestone is shown in the following table:

Analyses of Stones River formation, Murat Post-Office, Va.

(Wm. M. Thornton, Jr., Analyst.)

	I.	II.
	Per cent.	Per cent.
Silica (SiO_2)	2.54	5.20
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3) }	1.24	2.01
Magnesia (MgO)	0.49	——
Lime (CaO)	53.13	——
Magnesium carbonate ($MgCO_3$)	1.03	3.20
Calcium carbonate ($CaCO_3$)	94.88	89.03
Total	99.69	99.44

I. Massive dove limestone from lower beds.
II. Dark blue limestone from upper part of formation.

The weathered outcrops of the upper member of this limestone in the vicinity of Lexington, Va., have yielded a considerable variety of silicified fossils, among which the following species have been observed:

Partial list of fossils in the Stones River limestone, one mile west of Lexington, Va.

Anolotichia impolita.
Monotrypa sp.
Batostoma cf. *varians.*
Orthis tricenaria var.
Dalmanella cfr. *subequata.*
Dinorthis platys.
Camerella volborthi var.
Orthoceras olorus.
Bucania sulcatina.
Plæsiomys strophomenoides.
Herbertella costalis.

Murat limestone.—The Murat and Liberty Hall limestones, succeeding the Stones River strata, correspond in a general way to the Chambersburg formation of the more northern parts of the Valley, although lithologically no trouble will be encountered in separating these different divisions. The massive gray, coarsely crystalline, rather pure limestone of the Murat in particular is so different from the associated strata that the lithology alone should be sufficient for its discrimination. Fossils are abundant in the Murat, but no easily recognized characteristic forms have so far been detected. Some of the layers are crowded with ramose bryozoa, others contain numerous white nodular masses of the organism *Solenopora compacta*. the groundmass of the rock in each case being coarsely crystalline gray limestone. Fossils of other classes are not so abundant, although species of trilobites, namely *Illænus* sp., *Thaleops ovatus?*, *Platymetopus* cfr. *minganensis*, and *Platymetopus* n. sp., have been noted.

The important outcrops of the Murat are given on the maps accompanying the discussion of the counties of central western Virginia. In general it occurs as a narrow strip along the larger areas of Liberty Hall limestone. Geographically the Murat, as a distinct lithologic unit, is limited to Augusta, Rockbridge, and Botetourt counties. Paleontologically the fauna is essentially the same as the underlying upper member of the Stones River formation, that is, it is Chazy in character. Altogether the formation must be considered as a lens of marble-like limestone restricted to central western Virginia.

Disintegration of the Murat limestone results in a deep red clayey soil which is markedly distinct from the gray, cherty soil of the Natural Bridge formation, and likewise quite different from the brownish clays produced by weathering of the Liberty Hall strata.

The limestone, as a whole, runs very high in calcium carbonate, and, for this reason, it is the source of the lime burned at several points in central western Virginia. The lower portion often shows chert nodules upon weathering, and it was from this part that the sample in the following table, giving a high silica content, was obtained. About 125 feet of the Murat limestone are exposed at its type locality, but frequently the thickness is not so great. Variations in composition are shown in the table of analyses:

Analyses of Murat limestone.

(J. H. Gibboney, Analyst.)

	I.	II.	III.	IV.	V.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Silica (SiO_2)	1.80	5.92	11.72	1.58	1.62
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3) }	0.22	0.48	6.16	0.34	0.72
Lime (CaO)	54.50	52.00	44.14	54.40	54.18
Calcium carbonate ($CaCO_3$)	97.32	92.85	78.82	97.14	96.71
Magnesia (MgO)	0.07	0.40	1.28	0.91	0.42
Magnesium carbonate ($MgCO_3$)	0.15	0.84	2.69	1.91	0.90
Total	99.49	100.09	99.39	100.97	99.95

I. Eagle Mountain, Virginia.
II. Cut along Baltimore and Ohio Railway, northeastern edge of Staunton, Virginia.
III. Railroad cut, Mint Springs, Virginia.
IV. Four miles northeast of Greenville, Virginia.
V. Near Lexington, Virginia.

Liberty Hall formation.—A considerable portion of Rockbridge county, Virginia, is underlaid by dark argillaceous strata conspicuously displayed in the bluffs along the river in the vicinity of Lexington. Approximately 1,000 feet of these rocks are developed. Tracing these strata into northwestern Virginia, they disappear north of Augusta county, and are replaced in part by the Chambersburg formation. Southward they apparently grade into the Athens shale so imperceptibly that the necessity of the new name is not so apparent. This similarity of the Athens and Liberty Hall formations extends to their faunas as well. Each has a well marked but identical fauna in the lower part. Higher in the strata fossils are rare.

Professor Campbell's notes on the Liberty Hall formation are as follows:

"In describing a section through this region in 1879, J. L. Campbell used the name Lexington limestone for this formation, but inasmuch as the same name is given to certain Silurian rocks in Kentucky, it has been rechristened Liberty Hall limestone from the name of an old historic ruin which is constructed on and of this rock, and which has been standing for more than a century and is as well known in this region as Lexington itself.

"The Liberty Hall limestone is usually a succession of rather evenly banded beds of fine-grained, dark blue limestone and darker, more argillaceous limestone which weathers shaly. As we ascend into the formation calcareous shale predominates and limestone beds are less frequent. In this region the formation has been much fractured and folded, and some-

times appears massive with innumerable veins of infiltration of calcite filling the crevices. Again it appears shaly after long exposure to the weather. Brachiopods and trilobites of Trenton age are especially abundant in the lower beds. From the top of the Murat through the limestone and calcareous shale, so long as it carries conspicuous limestone beds, the Liberty Hall limestone is about 1,000 feet thick."

Reference to the Lexington section on page 106 indicates the presence of numerous fossils in the lower beds of the Liberty Hall limestone. The fauna here is a large one and only the species which have so far been identified with some certainty are included in the following list:

Partial list of fossils from the base of Liberty Hall limestone at Lexington, Va.

Ampyx cf. americanus.
Harpina ottawensis.
Illænus cf. consimilis.
Remopleurides canadensis.
Platymetopus minganensis.
Sphærexochus parvus.
Agnostus galba.
Christiania sp.
Hebertella bellarugosa.
Dinorthis (?) *platys.*
Dinorthis pectinella.
Triplesia sp.
Camerella cf. varians.
Scenella montrealensis.
Bucania cf. sulcatina.
Tetranota bidorsata.
Cyclora minuta.
Liospira lenticularis.

The Chazy character of this fauna is evident even from this partial list. A similar assemblage of species occurs at the base of the Athens shale at Athens, Tenn., and other Athens shale localities, so there seems little doubt of the correctness in correlating the Athens and Liberty Hall. The few fossils in the higher portions of both give no clue to their age, but the stratigraphic interval is that of the Lowville, Black River, and possibly early Trenton of the general time scale.

From the standpoint of cement materials, the Liberty Hall formation offers the best limestone of all the Ordovician formations. Some of its layers closely approach the ideal composition, while others need but the addition of the purer limestone in the associated Murat formation. The following series of analyses gives a fair idea of the range of composition. The individual strata are discussed more in detail in the description of the counties.

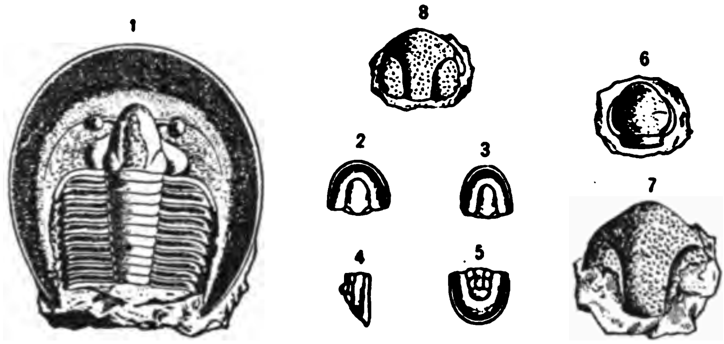


Fig. 10.—Trilobites of the Liberty Hall limestone.

1. *Eoharpes ottawensis* (Billings). In the Virginia examples, so far as found, only portions of the head are preserved.
2–5. *Agnostus galba* (Billings). 2, 3. Two cephala, × 2, showing variations in shape, probably due to compression. 4, 5. Side and front views of the pygidium, × 2.
6. *Remopleurides canadensis* (Billings). A glabella of this highly characteristic trilobite.
7, 8. *Amphilichas minganensis* (Billings). Two incomplete glabella showing slight differences in form.

These illustrations are copies of Billings' original figures.

Analyses of Liberty Hall limestone.

(J. H. Gibboney, Analyst.)

	I.	II.	III.	IV.
	Per cent.	Per cent.	Per cent.	Per cent.
Silica (SiO_2)	7.10	8.98	48.80	19.48
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3) }	0.92	1.02	7.60	2.74
Lime (CaO)	51.10	47.12	22.46	42.16
Calcium carbonate ($CaCO_3$)	91.25	84.14	40.11	75.29
Magnesia (MgO)	0.46	2.80	0.10	0.81
Magnesium carbonate ($MgCO_3$)	0.96	5.88	0.21	1.70
Total	100.23	100.02	96.72	99.21

	V.	VI.	VII.	VIII.
	Per cent.	Per cent.	Per cent.	Per cent.
Silica (SiO_2)	6.10	14.96	9.38	12.64
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3) }	0.98	0.94	1.02	1.82
Lime (CaO)	51.02	46.54	49.56	46.86
Calcium carbonate ($CaCO_3$)	91.11	83.11	88.50	83.66
Magnesia (MgO)	0.08	0.12	0.57	0.71
Magnesium carbonate ($MgCO_3$)	0.17	0.25	1.21	1.50
Total	98.36	99.26	100.11	99.62

I. Compact black argillaceous limestone, Eagle mountain, Virginia.
II. Gray compact limestone, Eagle mountain, Virginia.
III. Dark siliceous limestone, Eagle mountain, Virginia.
IV. Shaly limestone, Mt. Sidney, Virginia.
V. Coarsely crystalline limestone, Mt. Sidney, Virginia.
VI and VII. Fine-grained, dark blue limestone, Staunton, Virginia.
VIII. Subcrystalline limestone, eastern foothills, Little North mountain, Augusta county, Virginia.

Ordovician (Lowville and Trenton) limestones.—The foregoing discussion of the stratigraphic succession in central western Virginia relates only to the area east of North mountain, or to the Great Valley proper. Several anticlines in Highland and Bath counties west of North mountain expose Middle Ordovician strata as their lowest rocks. Because of poor railroad facilities these areas are of slight importance at present and their strata have not been studied in any detail. Enough is known, however, to state that the Lowville and Trenton of the New York classification are represented here by dove and black limestones respectively, in place of the shaly Liberty Hall formation. In the description of Bath county, the section most conveniently reached, namely, that at Hot Springs, is discussed in some detail.

Martinsburg shale.—The Federal Geological Survey has used this term in folio work in central western Virginia for the Upper Ordovician shales. The use of the term is here continued, although it is recognized that the equivalent Sevier shales of more southern localities could also be applied with equal correctness. These shales are described in some detail in the stratigraphy of both northwestern and southwestern Virginia, and it seems unnecessary to do more than mention them at this point. Most of the Martinsburg shale outcrops in central western Virginia are far from railroads, and at present have little economic value. A sample of the more calcareous phase of this shale was analyzed with the following results:

Analysis of highly calcareous shales, basal beds of Martinsburg. 2 miles west of Rockbridge Baths, Va.

(J. H. Gibboney, Analyst.)

	Per cent.
Insoluble	28.60
Organic matter	1.32
Iron oxide (Fe_2O_3)	2.33
Alumina (Al_2O_3)	2.53
Lime (CaO)	35.08
Calcium carbonate ($CaCO_3$)	62.64
Magnesia (MgO)	1.14
Magnesium carbonate ($MgCO_3$)	2.39
Total	99.81

EXPLANATION OF PLATE XIV.

These figures, copied from various sources, are of fossils from beds equivalent to the Virginia formations.

Figs. 1–6.—Fossils of the Eden formation (upper portions of the Sevier shales in southwestern Virginia, and of the Martinsburg shales in central western and northwestern part of the State).

1, 2. *Plectambonites sericeus* (Sowerby). Views of a wide variety of this cosmopolitan species (1) of a specimen showing the ventral side, and (2) of the inner side of another ventral valve.

3. *Callopora sigillarioides* (Nicholson). Magnified two diameters. A branch of this highly characteristic bryozoan. The smooth surface, composed of elongate-rounded cells with small separating pits or mesopores, will distinguish this form, even in casts.

4–6. *Dalmanella multisecta* (James). Natural size. Many layers, particularly the more sandy upper portions of the Eden shales in Virginia, are often crowded with entire shells or casts of a small brachiopod similar in all respects to the Ohio Valley form here figured. Figure 4 is a view of an entire shell seen from the ventral side, figure 5 a view along the hinge line of the same shell, and figure 6 represents the internal character of a dorsal valve.

Figs. 7–17.—Fossils of the Lorraine formation (Bays sandstone) of southwestern Virginia and lower part of the Massanutten sandstone in the remaining portions of western Virginia.

7. *Byssonychia radiata* (Hall). An average specimen of this rather common pelecypod; natural size.

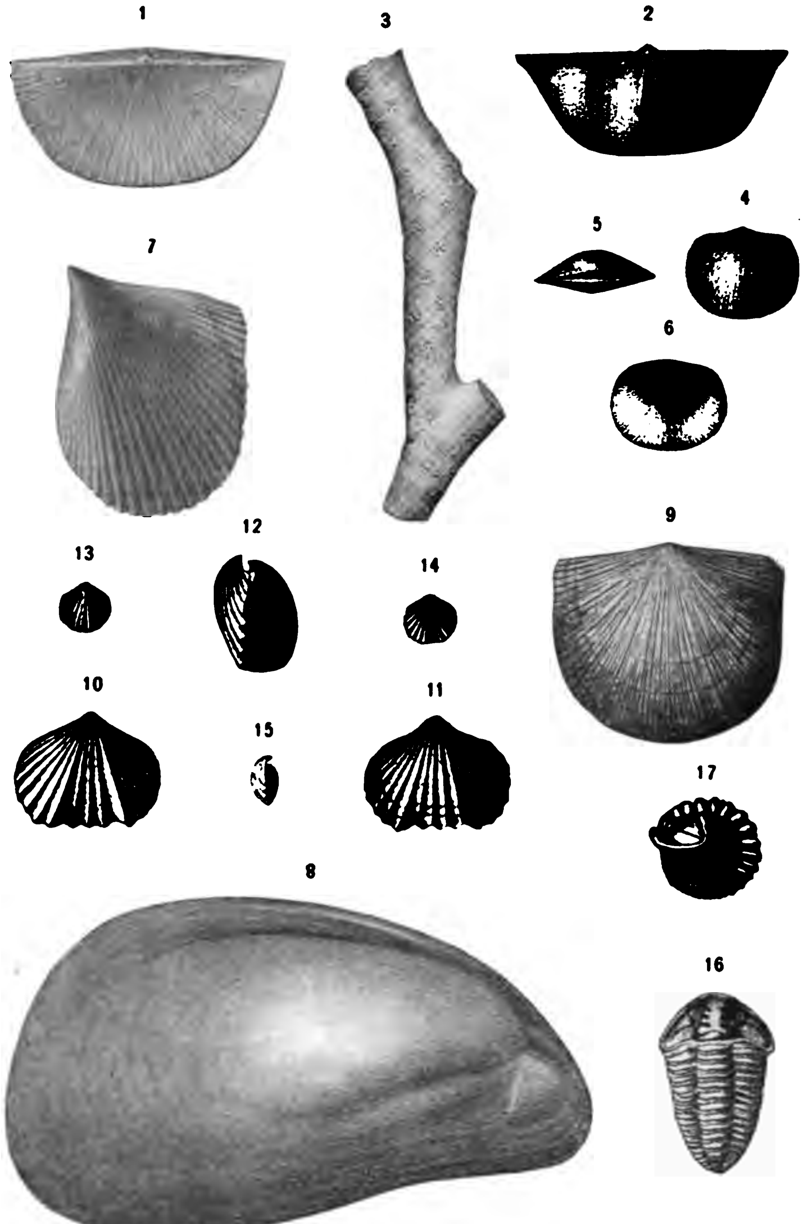
8. *Modiolopsis modiolaris* (Conrad). View, natural size, of an impression of the interior of a right valve. In the more shaly strata, the shell of this species is often represented by a thin black film.

9. *Rafinesquina alternata* (Conrad). A rather small specimen of this abundant brachiopod. Its thin, flat shells are easily recognized.

10–12. *Orthorhynchula linneyi* (James). Ventral, dorsal, and edge views, respectively, of a brachiopod found especially abundant in the Bays sandstone. The Virginia specimens are often larger than the figured example and have been uniformly wrongly identified as *Rhynchonella capax*.

13–15. *Zygospira modesta* (Say). Ventral, dorsal, and side views, natural size, of this small brachiopod.

16, 17. *Calymene callicephala* (Green). Entire example, one extended and the other enrolled, of this trilobite. Fragments, especially of the cephalon or head, are not uncommon at many Virginia localities.



CHARACTERISTIC FOSSILS OF UPPER ORDOVICIAN FORMATIONS.

Fig. 1.—House Mountains, Rockbridge county. View from Rich Hill, looking across valleys of Liberty Hall limestone and hills of Natural Bridge limestone. The mountains are capped by the Massanutten quartzite and the slopes show the Martinsburg shale.

2.—Fold in Massanutten sandstone, C. & O. railroad, Eagle Mountain.

USE MOUNTAINS AND FOLDED MASSANUTTEN SANDSTONE

Massanutten sandstone.—The closing strata of Ordovician time in central western Virginia are red and white sandstone so similar to strata occupying the same stratigraphic position in the other parts of the state that their description need not be repeated. Fossils are most abundant in the lower red beds—the equivalent of the more southern Bays sandstone. The upper white quartzites and massive sandstones hold *Arthrophycus* and *Scolithus* only, and their age must be considered still doubtful. Figures showing the characteristic fossils of each division are given on plates VIII and XIV. Neither analyses nor detailed sections of these strata were made.

DISTRIBUTION BY COUNTIES OF CEMENT MATERIALS IN CENTRAL WESTERN VIRGINIA.

AUGUSTA COUNTY.

The general geology of approximately the western two-thirds of this county has been mapped in the Staunton folio of the U. S. Geological Survey (No. 41). In this publication, however, the purer and argillaceous Ordovician limestones have not been separated from the general Shenandoah group but for the present purpose the map is of use in outlining the limits of the Martinsburg shale and underlying limestones. Maps showing the occurrence of the more important lines of outcrop of the Ordovician limestone in this county are presented on pages 85 and 124. From these it will be noted that these limestones are brought to the surface along the flanks of the Massanutten mountain syncline and along the foothills of Little North mountain on the western side of the Valley. The first of these areas is of more importance at present on account of railroad facilities.

With the exception of the northernmost part, the sequence of strata in Augusta county is essentially the same as that described under the stratigraphy of central western Virginia. Along the eastern flank of the Massanutten mountain syncline, faulting sometimes cuts out the purer limestones so that the dolomitic strata occur in contact with the shale. The western flank of this syncline usually shows the normal sequence, but at several points along this line of outcrop the argillaceous, Liberty Hall limestone is missing. Whether this formation was never deposited or was faulted out at these particular localities could not be determined in the short time employed in their study. In the vicinity of Greenville the Massanutten mountain syncline ends so far as the exposure of the Ordovician limestone and shales are concerned. South of this village in Augusta county cement

materials of this age are not to be had. Faulting in the northern part of the county along the western edge of the Valley cuts out the Ordovician limestones of economic value until a point south of Buffalo Gap is reached. From this place southward the limestones and shales are well exposed and afford abundant cement materials.

Mount Sidney and vicinity.—From Staunton to Mount Sidney and thence for several miles northeast the Valley Branch of the Baltimore and Ohio railroad either closely parallels or cuts through the belt of argillaceous limestone brought up on the western flank of the Massanutten mountain syncline. The same rocks reappear on the eastern flank, three to four miles distant. The intervening country is occupied by Martinsburg shale, all of the younger rocks found on Massanutten mountain having been removed by erosion. The favorable composition of the rock and the proximity of these two belts to railroads—the western to the Baltimore and Ohio, and the eastern to the Norfolk and Western—cause them to be worthy of attention. The following analysis of a sample from the eastern belt in the vicinity of Weyers Cave shows more magnesia than the average, although otherwise the composition is very favorable.

Analysis of argillaceous limestone, near Weyers Cave, Va.

(Wirt Tassin, Analyst.)

	Per cent.
Silica (SiO_2)	14.62
Alumina (Al_2O_3), Iron oxide (Fe_2O_3)	6.90
Calcium carbonate ($CaCO_3$)	67.92
Magnesium carbonate ($MgCO_3$)	4.69
Water (H_2O)	3.94

The section exposed along the railroad at Mt. Sidney and vicinity is as follows:

Geologic section, Mount Sidney, Va.

		Feet.
6.	Typical Martinsburg shale.	
5.	Calcareous shales and shaly limestone with few fossils	200+
4.	Brown shales with graptolites	60
3.	Gray coarsely crystalline limestones yielding some chert upon weathering	70
2.	Heavily bedded dark blue limestone	100+
1.	Dolomitic limestone.	

The northern part of Augusta county is believed to show overlaps between the strata of northwestern and central western Virginia. Although the fossils were comparatively few in the strata of the Mount Sidney section enough were found to indicate the probable correctness of the following correlation. Bed 1 represents the usual Natural Bridge limestone; bed 2,

the Stones River formation; bed 3, the Murat limestone of central western Virginia, and beds 4 and 5 held a few of the fossils characteristic of the Chambersburg formation. Of these different beds, numbers 3 and 5 appeared to be of most importance as a source of cement material, and therefore samples for analysis were collected from them alone.

Analyses of limestones, Mt. Sidney section.

(J. H. Gibboney, Analyst.)

	I.	II.
	Per cent.	Per cent.
Insoluble	19.48	6.10
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3)	2.74	0.98
Lime (CaO)	42.16	51.02
Calcium carbonate ($CaCO_3$)	75.29	91.11
Magnesia (MgO)	0.81	0.08
Magnesium carbonate ($MgCO_3$)	1.70	0.17
Total	99.21	98.36

I. Shaly limestone, bed 5 of section.
II. Coarsely crystalline limestone, bed 3 of section.

Fort Defiance.—Between this station and Mount Sidney the railroad passes over either the lower calcareous beds of the Martinsburg shale or the underlying argillaceous limestone, with exposures of these strata at several points. Here the rocks dip steeply to the east so that their entire thickness is crossed in a short distance. At Fort Defiance a section exposed along the road crossing the railroad showed a thickness of 300 feet of argillaceous limestones or calcareous shales, followed by the usual Martinsburg shale and underlaid by 100 feet or less of purer limestone. An unweathered sample of this argillaceous bed gave the following upon analysis:

Analysis of calcareous shale, Fort Defiance. Va.

(J. H. Gibboney, Analyst.)

	Per cent.
Insoluble	34.98
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3)	3.96
Lime (CaO)	31.80
Calcium carbonate ($CaCO_3$)	56.78
Magnesia (MgO)	1.42
Magnesium carbonate ($MgCO_3$)	2.98
Total	98.70

Churchville.—Between this place and Staunton, about 4 miles northwest of the latter, a narrow syncline of Martinsburg shale is found extending in a north and south direction for about four miles. Exposures of these shales commence just west of Galena and continue westward for about a mile. In several places they are intersected by narrow blocks of limestone and the rocks in general indicate considerable disturbance. Dolomitic strata only were noticed along the eastern edge of this belt, but the fossiliferous Ordovician limestones were found outcropping along the western side. Lack of transportation facilities as well as topographic reasons causes this small area to be of little promise economically.

Staunton.—East and northeast of this city the argillaceous limestones are well developed, and, together with the shales and pure limestones near by, offer abundant raw material for the manufacture of cement. The railroad facilities at Staunton are exceptionally good, for here a plant could obtain coal and ship its products over several lines. Ordinarily coal could be had on the most favorable terms over the Chesapeake and Ohio, but in times of labor disturbances in the New River field the fuel supply could still be obtained from the Fairmont region. The purer limestones in the vicinity of Staunton, as a rule, run unusually high in lime, so that shales or clays for mixture with them will be necessary. Unlimited quantities of shale may be found in connection with the limestone, but deposits of good clays are not so common. In this region the lower part of the shales are unusually calcareous, as the following analyses will show, but higher up in the series the percentage of lime is very small:

Analyses of Martinsburg shale and Liberty Hall limestone, vicinity of Staunton, Va.

(Charles Catlett, Analyst.)

	I.	II.	III.	IV.
	Per cent.	Per cent.	Per cent.	Per cent.
Silica (SiO_2)	19.28	19.92	23.08	10.28
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	9.86	10.76	10.08	32.80
Lime (CaO)	36.42	37.05	35.89	4.36
Magnesia (MgO)	1.08	1.72	0.94	45.79
Carbon dioxide (CO_2)	31.70	——	——	0.79

I–III. Calcareous shales showing variation in composition.
IV. Liberty Hall limestone.

The Ordovician section in the vicinity of Staunton is best seen along the Baltimore and Ohio railroad tracks and the road beyond the ice factory on the northeastern side of the city. Here it will be noted that the region is much folded and faulted, but through the aid of several sections the following succession can be determined:

Geologic section, Staunton, Va.

		Feet.
4.	Martinsburg shale. Brown and yellow shales, calcareous at base......	——
3.	Liberty Hall limestone. Fine-grained, argillaceous, unfossiliferous limestone	325±
2.	Murat limestone. Gray coarsely crystalline limestone crowded with *Solenopora* and bryozoa........	100
1.	Natural Bridge limestone. Gray dolomitic strata with a few layers of purer limestones........	——

All of the above formations of the Staunton section furnish cement materials, but the most important and abundant rock is to be had from the Liberty Hall limestone. Notes and analyses of the various divisions are given below.

Natural Bridge limestone.—The Cambrian dolomitic limestone forming the lower part of this division grade upward imperceptibly into another series of strata having essentially the same composition, but differing in that extensive layers of chert are interbedded with the usual dolomites. The areas occupied by this division may usually be recognized by their topographic features, for the cherts give rise to conspicuous hills or ridges. Chestnut Ridge, Sugar Loaf, and Betsey Bell are examples of this topography in the vicinity of Staunton. The age of this portion, which is particularly well exposed about Staunton, has been determined as Beekmantown from the gastropod and cephalopod remains found at various points in the Valley, but particularly in the vicinity of Lexington, Va.

Usually no pure limestone layers of any consequence have been noticed in this division, and this, as well as the unfavorable topography often accompanying its exposures, causes the rocks of this age to be of little value as a source of Portland cement rock. Still, in a few instances, lenses of comparatively pure limestones have been found in this formation as well as in the underlying Cambrian. The following analysis of a sample of this purer rock from the vicinity of Staunton is typical:

Analysis of rather pure limestone (Beekmantown) from vicinity of Staunton, Va.

(Charles Catlett, Analyst.)

	Per cent.
Silica (SiO_2)	1.79
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3) }	0.74
Lime (CaO)	50.36
Magnesia (MgO)	1.79
Carbon dioxide (CO_2)	41.36
Alkalies, etc.	3.97
Total	100.01

Analyses of the dolomitic beds of the Natural Bridge limestone have been published by Professor Rogers from samples collected in the vicinity of Staunton, Va.

Analyses of Natural Bridge limestone, vicinity of Staunton, Va.

	I.	II.	III.
	Per cent.	Per cent.	Per cent.
Calcium carbonate ($CaCO_3$)	15.13	17.44	14.64
Magnesium carbonate ($MgCO_3$)	11.87	10.03	11.24
Silica (SiO_2)	2.00	1.70	2.88
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3) }	0.56	0.26	0.47
Water	0.12	0.18	0.11
Loss	0.32	0.39	0.66
Total	30.00	30.00	30.00

I. Bluish gray, compact, slaty limestone from Chimney rocks, also called the Cyclopean towers, 15 miles west of Staunton.
II. Limestone of lead gray color, from hill near Staunton.
III. Bluish gray compact limestone from 4 miles west of Staunton.

Murat limestone.—This marble-like limestone is particularly well exposed along the Baltimore and Ohio railroad just northeast of Staunton, where a more or less complete section of the formation may be seen. The coarsely crystalline character and light gray color of the rock cause it to be easily recognized. Fossils, especially the *Solenopora* and bryozoa, are particularly abundant. Some of the layers weather into a considerable amount of chert, but as a rule the strata run high in lime.

Analysis of Murat limestone, Baltimore and Ohio railroad just northeast of Staunton, Va.

(J. H. Gibboney, Analyst.)

	Per cent.
Insoluble	5.92
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	0.48
Lime (CaO)	52.00
Calcium carbonate ($CaCO_3$)	92.85
Magnesia (MgO)	0.40
Magnesium carbonate ($MgCO_3$)	0.84
Total	100.09

Liberty Hall limestone.—On account of the faulted condition of the Staunton area the entire thickness of this formation could not be determined, but it is probably not less than 325 feet. The lithologic character of these strata is somewhat similar to some of the Lehigh Valley cement rock, but judging from the analyses below, shale will have to be added to make a good cement mixture.

Analyses of Liberty Hall limestone, vicinity of Staunton, Va.

(J. H. Gibboney, Analyst.)

	I.	II.
	Per cent.	Per cent.
Insoluble	14.92	9.38
Organic matter	——	0.24
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	0.94	1.02
Lime (CaO)	46.54	49.56
Calcium carbonate ($CaCO_3$)	83.11	88.50
Magnesia (MgO)	0.12	0.57
Magnesium carbonate ($MgCO_3$)	0.25	1.21
Total	99.26	100.35

Martinsburg shale.—Analyses prepared by Mr. Catlett from samples of the lower part of the Martinsburg shale have been given on a previous page. These indicate that this division of the shales in the vicinity of Staunton agrees with the same horizon elsewhere in chemical composition, the high amount of lime being the noteworthy feature. The higher members of the shale in the region east of Staunton show the same lithologic and other characters described for central western Virginia in general.

Massanutten mountain syncline south of Staunton.—This great fold ceases as a geologic feature of the Valley in the region between Staunton

and Greenville, the Martinsburg shale of this syncline showing for the last time at a point just north of the latter place. South of Greenville a new arrangement of the rocks obtains and the profound folding and faulting characteristic of the areas still farther south are encountered.

The geologic sequence of the region under discussion is more or less doubtful to the writer because of a lack of time for thorough study. Along the western edge of the syncline south of Staunton, the less calcareous and therefore higher divisions of the Martinsburg shales were found in every instance, where examination was made, to rest upon the Murat limestone. The same condition obtained along the eastern side except at such places where the dolomitic limestone had been clearly overthrust upon the shales. Whether the absence of the Liberty Hall limestone and the lower calcareous portions of the shales in these instances was due to non-deposition or to faulting could not be determined, although the evidence in hand favors the former view. South of Greenville, in the vicinity of Raphine, a small strip of Martinsburg shale occurs, resting apparently upon still lower limestones —some portion of the Natural Bridge formation—so it would appear that some time during the Ordovician, this part of the Valley had been land.

The only sources of cement material in this particular area, therefore, is the Murat limestone and the Martinsburg shale. No samples of the latter were taken for analysis, but the physical characters and general aspect of the material is so much like the same rock at Staunton that the composition would probably be similar to that given on page 116. The character of the Murat limestone here is also quite similar to that of the Staunton area. The particular sample from which the following analysis was made came, as shown by the figures, from a stratum more siliceous than usual.

Analysis of Murat limestone, Mint Spring, Va.

(J. H. Gibboney, Analyst.)

	Per cent.
Insoluble	11.72
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	6.16
Lime (CaO)	44.14
Calcium carbonate ($CaCO_3$)	78 82
Magnesia (MgO)	1.28
Magnesium carbonate ($MgCO_3$)	2.69
Total	99.39

At the southern end of the syncline, in the area northeast of Greenville, rather numerous exposures of the Murat limestone may be found. Here the formation, as indicated in the following analysis, runs high in lime. The cement materials of the western edge of the syncline are within short

distances of transportation facilities. Indeed for a number of miles the Baltimore and Ohio railroad closely parallels the line of shale outcrop, and in the vicinity of Folly Mills and Mint Spring the railroad cuts are in the Murat limestone itself.

Analysis of Murat limestone, 4 miles northeast of Greenville, Va.

(J. H. Gibboney, Analyst.)

	Per cent.
Insoluble	1.58
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	0.34
Lime (CaO)	54.40
Calcium carbonate ($CaCO_3$)	97.14
Magnesia (MgO)	0.91
Magnesium carbonate ($MgCO_3$)	1.91
Total	100.97

Eastern edge of Massanutten mountain syncline.—The Ordovician limestones are seldom seen in this portion of Augusta county, mainly because of few exposures, but also on account of overthrust faulting. In the south central portion of the county, the section is normal along the eastern side of the Massanutten mountain syncline, but further north the usual occurrence is of the dolomitic Natural Bridge formation thrust upon the Martinsburg shale. The Portland cement resources here are therefore correspondingly few. The bands of natural cement rock noted in the discussion of more northern counties pass through the eastern part of Augusta county. An analysis of this rock, quoted from the "Geology of the Virginias," is as follows:

Analysis of light blue, compact, magnesian limestone, near Waynesboro, Va.

	Per cent.
Calcium carbonate ($CaCO_3$)	12.33
Magnesium carbonate ($MgCO_3$)	9.58
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	0.57
Silica (SiO_2)	2.36
Water	0.16
Total	25.00

Western edge of Valley.—The geologic structure of this part of Augusta county is quite similar to the same portion of the Valley further north. By overthrust faulting the dolomitic limestones are often found in contact

with the Martinsburg shale or higher formations, and the normal sequence of the rocks is found only in the foothills of Little North mountain in the southwestern part of the county. As shown on the general map, the shales may be found at almost any point along this western line of outcrop, but the argillaceous and pure Ordovician limestones occur only in the small area indicated. The geologic relations of this part of Augusta county are represented in the structure sections, figures 11 and 12.

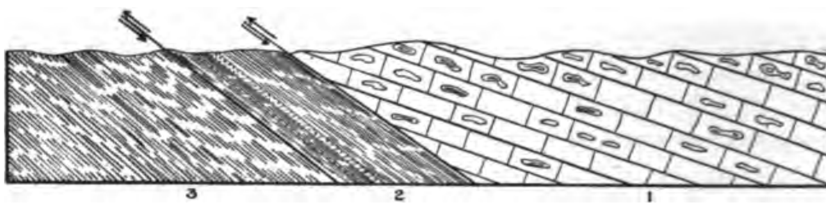


Fig. 11.—Structure section, western edge of Valley, south of Stokesville. 1. Knox dolomite; 2. Martinsburg shale; 3. Devonian shale.

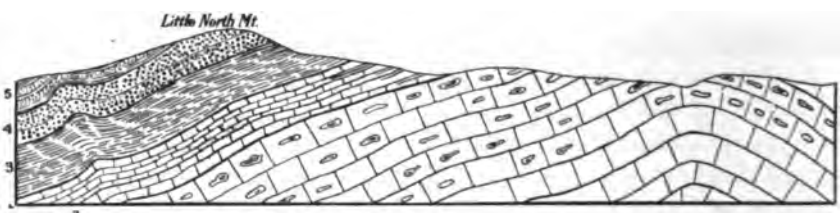


Fig. 12.—Structure section, vicinity of Zach and Little North mountain, Augusta county. 1. Natural B idge limestone; 2. Middle Ordovician limestone; 3. Martinsburg shale; 4. Massanutten sandstone; 5. Rockwood formation.

A sample of the dark, compact, Liberty Hall limestone of this region gave the following analysis:

Analysis of Liberty Hall limestone, eastern foothills Little North mountain, southwestern part of Augusta county, Virginia.

(J. H. Gibboney, Analyst.)

	Per cent.
Insoluble	12.64
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3) }	1.82
Lime (CaO)	46.86
Calcium carbonate ($CaCO_3$)	83.66
Magnesia (MgO)	0.71
Magnesium carbonate ($MgCO_3$)	1.50
Total	99.62

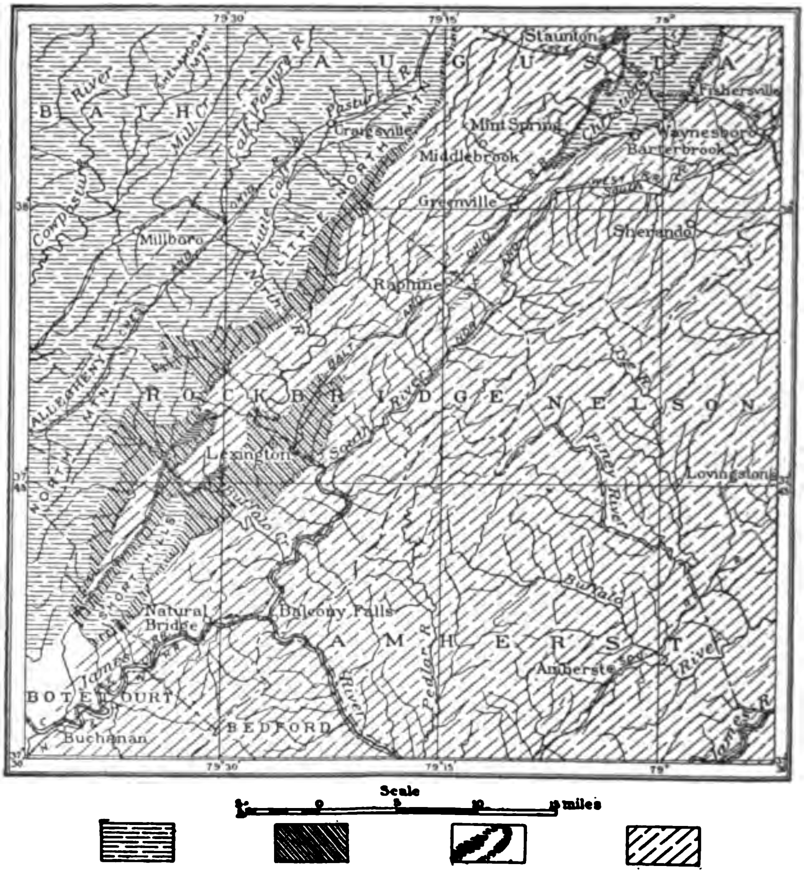
HIGHLAND COUNTY.

Two anticlines bringing the Ordovician limestones and shales to the surface are found in Highland county, but the distance from railroads and general inaccessibility of the region causes these strata to be of no present economic importance. Lewistown limestone also occurs, and for the same reason is of no immediate use. The detailed geology of a portion of Highland county has been mapped by Darton in the Monterey folio (No. 61), of the U. S. Geological Survey, and reference to this will show that the strata of the country occur in anticlines and synclines in which the lowest rocks exposed are the Ordovician limestones. Only two of these anticlines have been eroded deeply enough to expose the Ordovician limestone, but the Lewistown formation is more frequently shown. These areas of Ordovician strata are (1) one occupying the Valley between Little mountain, and (2) a smaller region of outcrop along Wilson Run, just west of Jack mountain. The stratigraphy of these areas is essentially the same as given in the Hot Springs section of Bath county. Numerous bands of the other important cement strata, the Lewistown limestone and the Romney shale, are found in Highland county. The arrangement of these various bands of outcrop is shown in the structure section on page 126.

ROCKBRIDGE COUNTY.

The map presented on page 124 indicates that proportionately, Rockbridge county is occupied by a larger amount of argillaceous limestones than any other county of the state. This is due partly to the close folding of this limestone in the more important area of outcrop, but mainly to the fact that since the time of folding, erosion has proceeded only to the point of exposing these argillaceous strata. Lexington is situated approximately in the central portion of this folded region, while an area in which the strata are more horizontal, and in which also the structure is less complicated, lies just east of Little North mountain. The composition of the rock in both of these general areas is such that theoretically the strata should yield a high grade Portland cement. However, as has been pointed out by Catlett, it is a question whether the relatively high ratio of silica to alumina and iron, tending to increase the refractory character of the clinker, is offset by the finely divided condition and intimate mixing of the natural material. Still, in spite of this possible objection to the use of the rock, Rockbridge county must be considered as one of the most promising sources of cement rock in western Virginia.

The composition of the argillaceous and other limestones of the county are presented under the more detailed discussion of localities.



Martinsburg shale and overlying formations.

Liberty Hall limestone (cement rock).

Murat limestone.

Natural Bridge limestone and underlying formations.

Fig. 13.—Map of the Valley of Virginia from Staunton to Natural Bridge. Area marked by diagonal broken lines includes Natural Bridge and underlying formations.

Analyses of the dolomitic limestones from various parts of Rockbridge county have been published in the "Geology of the Virginias," by Professor Rogers, whose results are as follows:

Analyses of dolomitic limestones, Rockbridge county, Virginia.

	I.	II.	III.	IV.
	Per cent.	Per cent.	Per cent.	Per cent.
Calcium carbonate ($CaCO_3$)	17.36	10.77	20.81	12.53
Magnesium carbonate ($MgCO_3$)	9.87	7.58	5.18	8.97
Silica (SiO_2)	2.13	8.07	3.81	2.82
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3) }	0.25	3.08	0.66	0.52
Water	0.08	0.32	0.15	0.16
Loss	0.31	0.18	0.39	——
Total	30.00	30.00	30.00	25.00

I. Light gray limestone from North river above the mouth of Buffalo creek, Rockbridge county.
II. Dark blue limestone from a band near the preceding.
III. Blackish blue limestone from Natural Bridge and banks of Cedar creek.
IV. Bluish gray limestone from locality 1½ miles east of Cedar Grove, Rockbridge county.

Lexington.—As noted previously, Lexington is situated in the central portion of the eastern area of outcrop. Here the entire section can be studied in detail, and for this reason many of the samples for analysis were selected from Lexington or its immediate vicinity. The close folds exhibited by the Liberty Hall limestone in the vicinity of Lexington are overturned to the west so that the strata show a fairly uniform eastward dip. This folding likewise causes the rocks to have apparently a great thickness, but a careful examination will show the repetition of similar beds in regular order. In addition, the core of an anticline or syncline may be occasionally observed, and whenever it is possible to get a continuous section, a maximum thickness not exceeding that given by Professor Campbell is found. This close folding also involves the underlying Murat limestone, but because of the few and relatively unimportant exposures of this formation at the surface, it has been differentiated on the map only along the western border of the Lexington area.

The geologic section at Lexington has been given in detail on page 109, but is repeated below in condensed form for reference with the analyses.

Geologic section, Lexington, Va.

	Feet.
4. Liberty Hall formation.	
(d) Thin-bedded, argillaceous limestone and calcareous shales	500±
(c) Fine-grained, dark, massive argillaceous limestone with an obscure conchoidal fracture	250±
(b) Argillaceous knotty limestone	40
(a) Crystalline to subcrystalline limestone	10

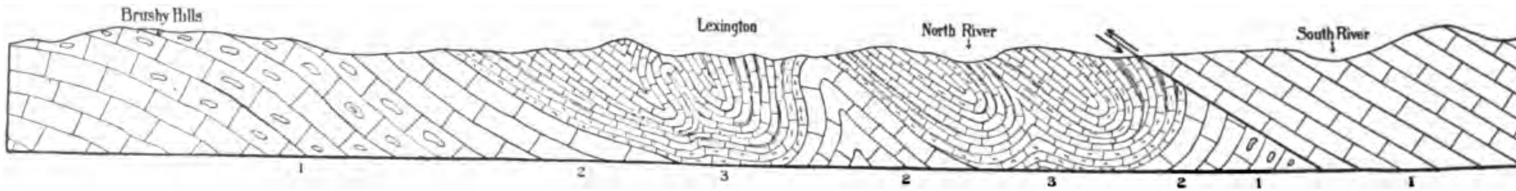


Fig. 14.—Structure section in the vicinity of Lexington, Virginia. 1. Natural Bridge limestone; 2 Murat limestone; 3. Liberty Hall limestone.

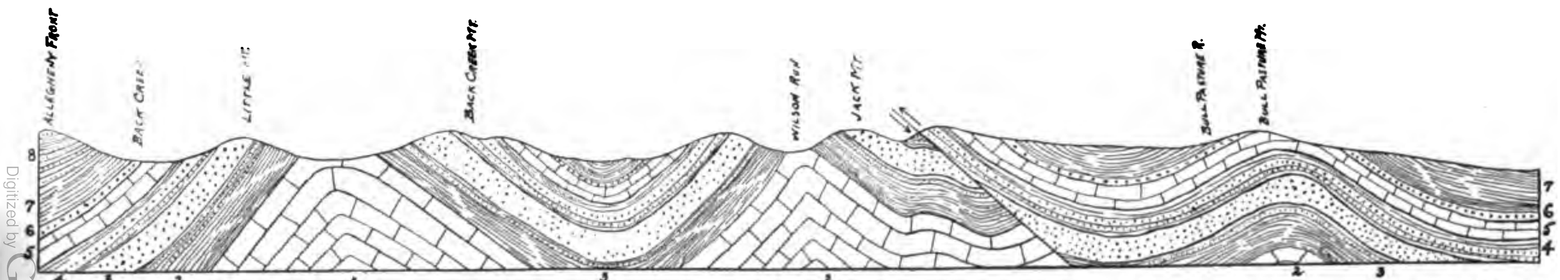


Fig. 15.—Structure section across a portion of Highland county. (Adopted from Folio 61, U. S. Geol. Survey.) 1. Ordovician limestone. 2. Martinsburg shale. 3. Massanutten sandstone. 4. Rockwood formation. 5. Lewistown limestone. 6. Monterey sandstone. 7. Romney shale. 8. Jenning's formation.

3. Murat formation.
   Massive gray crystalline limestone weathering into a red, clayey soil comparatively free from chert 100
2. Stones River limestone.
   (b) Massive, somewhat cherty limestone, seldom shown and of slight thickness. Fossils numerous .... ——
   (a) Massive dove limestone. Seldom present in the section and thickness slight when present .... ——
1. Natural Bridge limestone.
   Gray and light blue magnesian limestone weathering into chert. Conspicuous beds of chert near the top .... ——

Of the different divisions distinguished in the section, the Liberty Hall and Murat are the only formations worthy of consideration as a source of cement materials, the former as a cement rock itself, and the latter as a more or less pure limestone which could be used in mixtures. The occurrence of the other members of the section has already been noted in the discussion of the stratigraphy of central western Virginia, so that remarks at this point are unnecessary.

Mr. Charles Catlett has analyzed a series of samples from the Lexington strata, but the particular strata from which they were derived were not noted. In all probability I. of the subjoined table was from the Murat limestone, while II. to VI. represent various phases of the Liberty Hall beds.

Analyses of limestones from Lexington, Va.

(Charles Catlett, Analyst.)

	I.	II.	III.
	Per cent.	Per cent.	Per cent.
Silica (SiO_2)	0.73	9.31	11.86
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3) }	0.79	3.47	1.76
Lime (CaO)	53.71	46.30	46.64
Magnesia (MgO)	0.83	0.86	0.74
Carbon dioxide (CO_2)	——	——	38.32

	IV.	V.	VI.
	Per cent.	Per cent.	Per cent.
Silica (SiO_2)	12.92	17.42	22.60
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3) }	3.88	4.70	7.06
Lime (CaO)	45.14	42.44	36.72
Magnesia (MgO)	1.37	1.68	1.69
Carbon dioxide (CO_2)	37.20	35.62	32.52

Additional samples collected by the writer from particular horizons of the general section were analyzed with the results shown in the table below:

Analyses of Murat and Liberty Hall limestones, vicinity of Lexington, Va.

(J. H. Gibboney, Analyst.)

	I.	II.	III.	IV.
	Per cent.	Per cent.	Per cent.	Per cent.
Insoluble	1.62	4.32	10.24	1.30
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3) }	0.72	0.76	0.74	0.54
Lime (CaO)	54.18	52.06	48.16	54.28
Calcium carbonate ($CaCO_3$)	96.71	92.96	86.00	96.93
Magnesia (MgO)	0.42	0.94	1.00	0.36
Magnesium carbonate ($MgCO_3$)	0.90	1.97	2.10	0.76
Total	99.95	100.01	99.09	99.53

I. Compact white limestone, Murat formation, Reservoir Hill, Lexington, Virginia.
II. Subcrystalline limestone, base of Liberty Hall beds, near Lexington, Virginia.
III. Dark argillaceous limestone, Liberty Hall formation, Spring Cave Hill, Lexington, Virginia.
IV. Compact gray limestone, Liberty Hall formation, Spring Cave Hill, Lexington, Virginia.

Several miles east of Lexington, excellent exposures of the Liberty Hall limestone are found along the Chesapeake and Ohio railroad. Three samples, selected from various horizons at this point, show the following composition:

Analyses of Liberty Hall limestone, 2 miles east of Lexington. Va.

(Wm. M. Thornton, Jr., Analyst.)

	I.	II.	III.
	Per cent.	Per cent.	Per cent.
Silica (SiO_2)	12.42	12.29	10.97
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3) }	4.26	3.54	4.44
Lime carbonate ($CaCO_3$)	80.31	78.73	80.80
Magnesium carbonate ($MgCO_3$)	2.26	4.61	1.76
Total	99.25	99.17	97.97

Rockbridge Baths.—The second area of cement limestone in this county is a strip usually about two miles in width, just east of Little North

Fig. 1.—Overthrust fault in Tuscarora sandstone, near Panther Gap, Virginia.

Fig. 2.—Fields of residual decay in Shenandoah Valley, near Natural Bridge, Virginia.

OVERTHRUST FAULT AND LIMESTONE DECAY

mountain. Rockbridge Baths lies just east of this strip, so that for want of a better name to locate this area this is employed.

Analyses of limestones and shale, central western Virginia.

(J. H. Gibboney, Analyst.)

	I.	II.	III.	IV.
	Per cent.	Per cent.	Per cent.	Per cent.
Insoluble	24.12	30.24	17.86	28.60
Organic matter	——	——	0.14	1.32
Alumina (Al_2O_3)	2.22	4.56	1.60	2.53
Iron oxide (Fe_2O_3)				2.33
Lime (CaO)	40.24	33.00	41.34	35.08
Calcium carbonate ($CaCO_3$)	71.86	58.93	73.62	62.64
Magnesia (MgO)	0.05	2.72	3.03	1.14
Magnesium carbonate ($MgCO_3$)	0.10	5.81	6.38	2.39
Total	98.30	99.54	99.80	99.81

I. Murat formation, near Rockbridge Baths, Virginia.
II. Compact siliceous limestone, Liberty Hall formation, Kerrs creek, Virginia.
III. Argillaceous limestone, upper part of Liberty Hall formation, 5 miles west of Rockbridge Baths, Virginia.
IV. Highly calcareous shales, basal beds of the Martinsburg formation, 2 miles west of Rockbridge Baths, Virginia.

Murat Post-Office.—The various Ordovician formations are well exposed in this vicinity where the following succession of strata may be noted. This section has been given on a previous page but is repeated here in a somewhat abbreviated form for comparison with the analyses.

Geologic section, Murat Post-Office, Va.

	Feet.
Liberty Hall limestone:	
Fine-grained, dark argillaceous limestone, thin-bedded above, more massive below	1,000
Murat limestone:	
Massive, coarsely crystalline, gray limestone	125
Stones River formation:	
Massive, dark blue, comparatively pure subcrystalline limestone with a few magnesian layers	20
Laminated blue to drab mottled limestone	14
Thin-bedded dark blue magnesian limestone with thin bands of solid, black, platy chert	9
Massive dove limestone	6
Natural Bridge (Beekmantown):	
Rather massive magnesian limestone weathering into laminated strata bearing porous sandy chert	——

The massive dove limestone forming the lowest portion of the Stones River formation showed as usual a high lime content, as noted in the following analysis:

Analysis of massive dove limestone, Stones River formation, Murat Post-Office, Va.

(Wm. M. Thornton, Jr., Analyst.)

	Per cent.
Silica (SiO_2)	2.54
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	1.24
Magnesia (MgO)	0.49
Lime (CaO)	53.13
Magnesium carbonate ($MgCO_3$)	1.03
Calcium carbonate ($CaCO_3$)	94.88
Total	99.69

The upper portions of the Stones River formation are less pure as a rule and are almost always magnesian or argillaceous. The sample selected as average for these upper beds, however, showed more calcium carbonate than anticipated.

Analysis of dark blue limestone, upper part of Stones River formation, Murat Post-Office, Va.

(Wm. M. Thornton, Jr., Analyst.)

	Per cent.
Silica (SiO_2)	5.20
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	2.01[a]
Magnesium carbonate ($MgCO_3$)	3.20
Calcium carbonate ($CaCO_3$)	89.03
Total	99.44

The purest limestone of this region occurs in the Murat formation, which here attains a considerable thickness. A sample from the lower part of this limestone gave the following results upon analysis, but, judging from field notes, the higher beds are equally pure:

Analysis of coarsely crystalline white limestone, Murat formation, Murat Post-Office, Va.

(Wm. M. Thornton, Jr., Analyst.)

	Per cent.
Insoluble residue	0.49
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	0.60
Calcium carbonate ($CaCO_3$)	97.98
Magnesium carbonate ($MgCO_3$)	0.84
Total	99.91

[a] Contains P_2O_5.

The black argillaceous limestone and shale making up the Liberty Hall formation occur in abundance in the vicinity of Murat post-office. The samples selected for testing show a considerable variation in the silica and iron-alumina content.

Analyses of Liberty Hall limestone. Murat Post-Office, Va.

(Wm. M. Thornton, Jr., Analyst.)

	I.	II.	III.	IV.
	Per cent.	Per cent.	Per cent.	Per cent.
Silica (SiO_2)	8.096	11.03	1.67	7.99
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3) }	3.30	1.97	1.40	2.72
Magnesia (MgO)	2.32	1.59	2.51	1.81
Lime (CaO)	45.74	46.94	50.88	47.64
Magnesium carbonate ($MgCO_3$)	4.85	3.335	5.24	3.79
Calcium carbonate ($CaCO_3$)	81.68	83.82	90.87	85.05
Total	97.926	100.15	99.18	99.58

BATH COUNTY.

The Ordovician limestones and shales are brought to the surface in two instances only in this county. The first is along an anticline passing through Warm Springs and Hot Springs southwestward and terminating in the northeastern part of Alleghany county. The southern portion of a similar anticline in Highland county likewise terminates in the northern part of the area under discussion. Pure and argillaceous limestones and calcareous shales outcrop in abundance along the lines indicated, but the location of these strata and the topography of the country are such that it is doubtful if the materials will ever become of use. Railroad facilities are found at Hot Springs, but no samples of the limestone were analyzed, and the following notes on the stratigraphy are introduced mainly for comparison.

The lowest beds exposed in the Hot Springs anticline are massive blue and dove limestones with many of the layers mottled with dove-colored streaks. These yield little chert and are probably high grade limestones. Above these are dark blue, somewhat cherty limestones passing upward into massive and shaly dove-colored strata holding an abundance of fucoidal remains, ostracoda, and gastropoda. These fossiliferous layers are succeeded by a very characteristic dove limestone some fifty feet in thickness, crowded with a loosely growing *Tetradium*. All of the beds described above

probably belong to the Stones River formation, and are not less than a thousand feet in thickness. None of the Knox limestones with the characteristic chert was observed in this section.

Four hundred feet of yellow drab and black shales with thin limestone layers follow the preceding limestone and in the usual classification of the Martinsburg would form the basal member of the formation. However, this division is so different lithologically and faunally that its separation from the succeeding shales is a matter of little difficulty. The fauna is of typical Trenton age, many of the limestone slabs being covered with the fossils of which a variety of *Dalmanella testudinaria* is most abundant. *Trinucleus concentrica, Prasopora simulatrix,* and the ostracoda *Tetradella subquadrata* and *Ceratopsis intermedia* are likewise abundant, especially in the middle and upper part.

Above these limestones and shales carrying Trenton fossils come the usual Martinsburg shales with a Utica fauna in the lower part and Eden fossils higher up. The Ordovician portion of the section is closed by the Massanutten sandstone which here has been subdivided by Darton into the Juniata, Tuscarora and Cacapon formations.

The Lewistown limestone also outcrops in Bath county, but for the reasons mentioned before it is likely to prove of little use. The Lewistown limestone has a more extended area of outcrop than the Ordovician rocks, but as these areas usually lie on the slopes of mountains, the strata are commonly covered with débris from above. The chemical character and distribution of this formation is described in a later chapter.

BOTETOURT COUNTY.

The railroads traversing this county are in general so far from the outcrops of Ordovician strata that the cement rock, although of essentially the same character as in Rockbridge county, cannot be considered of much immediate use. The principal line of outcrops follows the eastern foothills of North mountain and at only one point is this strip crossed by a railroad. This is at Eagle mountain where a good section may be seen along the James river and cuts of the Chesapeake and Ohio railroad. The succession of Ordovician strata here is essentially the same as at Lexington, Va., the cherty beds of the Natural Bridge limestone being succeeded by the light-colored pure limestone of the Murat, and this in turn by the argillaceous Liberty Hall limestone. The usual Martinsburg shale follows these argillaceous limestones and is succeeded in turn by the Bays and Clinch divisions

of the Massanutten sandstone. The Liberty Hall limestones at this locality are, however, but slightly developed, being apparently cut out in great part by faulting.

Analysis of Murat limestone, Eagle Mountain, Va.

(J. H. Gibboney, Analyst.)

	Per cent.
Insoluble	1.80
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	0.22
Lime (CaO)	54.50
Calcium carbonate ($CaCO_3$)	97.32
Magnesia (MgO)	0.07
Magnesium carbonate ($MgCO_3$)	0.15
Total	99.49

As shown by the above analysis, the Murat runs high in lime. Its use then in cement making would be more for mixture with shaly rocks than as a direct source of rock for manufacture. Extensive quarries are located in this limestone at Eagle Mountain Station.

Analyses of Liberty Hall limestone, Eagle Mountain, Va.

(J. H. Gibboney, Analyst.)

	I.	II.	III.
	Per cent.	Per cent.	Per cent.
Insoluble	7.10	8.98	48.80
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	0.92	1.02	7.60
Lime (CaO)	51.10	47.12	22.46
Calcium carbonate ($CaCO_3$)	91.25	84.14	40.11
Magnesia (MgO)	0.46	2.80	0.10
Magnesium carbonate ($MgCO_3$)	0.96	5.88	0.21
Total	100.23	100.02	96.72

I. Compact black, argillaceous limestone.
II. Gray, compact limestone.
III. Dark, siliceous limestone.

The greater portion of the Liberty Hall limestone at this locality is made up of compact, black strata with a tendency, especially when slightly weathered, to become shaly. Judging from the general aspect of the rock and preliminary tests in the field, its chemical composition is rather uniform. Analysis I. of the above table is of the best grade of this rock.

Associated with this black limestone are grayish and dark siliceous strata of which analyses II. and III. are representative. These strata, however, form a very small proportion of the formation, so that in general it may be said to be made up of black argillaceous limestone.

Analyses of four magnesian limestones from various parts of Botetourt county were published by Professor Rogers. These, in tabular form, are quoted below:

Analyses of magnesian limestones, Botetourt county, Virginia.

	I.	II.	III.	IV.
	Per cent.	Per cent.	Per cent.	Per cent.
Calcium carbonate ($CaCO_3$)	9.29	13.96	11.16	12.52
Magnesium carbonate ($MgCO_3$)	7.31	9.35	9.38	7.83
Silica (SiO_2)	6.93	2.09	3.59	3.90
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3) }	1.29	0.37	0.62	0.62
Water	0.18	0.33	9.25	0.13
Total	25.00	26.10	34.00	25.00

I. Dark bluish-gray limestone, 8 miles north of Fincastle, Va.
II. Light bluish-gray limestone from the eastern base of Price's mountain, Botetourt county.
III. Dark bluish-gray limestone from Catawba creek, near Stone Coal Gap.
IV. Dark bluish-gray limestone from Roaring Run, foot of the Two Pointers, Botetourt county.

ALLEGHANY COUNTY.

As in the other counties of Appalachian Virginia, the important limestones of Alleghany county are of Ordovician and Lewistown age. Here the Ordovician strata are limited to two small and unimportant areas. The first is the southern portion of the Hot Springs anticline mentioned as occurring in Bath county. This occupies a few square miles in the northern part of Alleghany county. The second area is considerably larger, but is equally inaccessible. This consists of an anticline just west of the Rich Patch mountains, heading in the vicinity of Rich Patch. The lithological features of these limestones are much as described in the Hot Springs section in Bath county.

Economically considered the most important Lewistown limestone outcrops are in the vicinity of Covington and Clifton Forge. These are discussed in a later chapter.

CRAIG AND ROANOKE COUNTIES.

Although several of the faults described later in the geology of southwestern Virginia cross these two counties and thus afford exposures of the Ordovician limestones and shales, the railroad facilities are so poor and the topography so unfavorable that at present their cement materials cannot be considered of much value. In Roanoke county, the most important strip of Ordovician strata follows the western slope of Paris mountain, while in Craig county, the valley of Sinking creek is occupied by an anticline of these strata. In the latter area the geologic section is essentially the same as the Pearisburg section discussed in Giles county. Reference to this section and the analyses accompanying it will give a fair estimate of the nature and composition of the limestones and shales in Craig county.

The nearest railroad facilities for the Roanoke county strip of outcrop are at Blacksburg. The succession of strata in this strip is very similar to the section described for the Blacksburg area.

Along the northwest slope of Catawba mountain, north of Salem, the cherty Knox dolomite is followed immediately by dark shales referred to the Athens shale of more southern localities. These in turn are succeeded by the brown Upper Ordovician shales, and finally the Bays and Clinch sandstones form the higher portions of the mountain. The purer limestones seem to be wanting entirely in this section, although farther south the rather pure Stones River strata are developed between the Knox dolomite and Athens shale.

A sample of the magnesian limestone of Roanoke county was analyzed by Professor Rogers, who published the following results:

Analysis of slaty limestone, Liberty Road, 3 miles north of Big Lick, Roanoke county, Virginia.

	Per cent.
Calcium carbonate ($CaCO_3$)	11.55
Magnesium carbonate ($MgCO_3$)	8.54
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3) }	1.00
Sulphuret of iron	0.23
Silica (SiO_2)	3.17
Water	0.50
Total	24.99

A single analysis was made of the dark shales correlated with the Athens shale, outcropping in the Valley northwest of Catawba mountain. Reference to this analysis will show that these shales have a fair composition from the standpoint of cement rock.

Analysis of Athens shale, near Catawba, Roanoke county, Virginia.

(Wm. M. Thornton, Jr., Analyst.)

	Per cent.
Silica (SiO_2)	23.56
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3) }	5.48
Magnesia (MgO)	0.88
Lime (CaO)	37.54
Magnesium carbonate ($MgCO_3$)	1.85
Calcium carbonate ($CaCO_3$)	67.03
Total	97.92

GENERAL GEOLOGY OF SOUTHWESTERN VIRGINIA.

The geologic features of this portion of Virginia were described and mapped by Prof. J. J. Stevenson in four articles published in 1881, 1885, and 1887.[a] Although these papers were essentially accounts of geological reconnoissances, yet the main structural lines of a considerable part of the area were indicated, and for this reason, especially, Professor Stevenson's work has been of great assistance to later students. Unfortunately for the purposes of the present paper, the Cambrian and Ordovician limestones and shales were mapped as a single unit.

Previous to Professor Stevenson's work, members of the geological corps of Virginia, under Prof. William B. Rogers, made several sections through this area, and later, Professor Lesley published notes upon the geology of several counties. In these instances, also, the Ordovician limestones are not distinguished. More recently the United States Geological Survey has published four folios, the Estillville, Tazewell, Bristol, and Pocahontas, in which the geology of portions of southwestern Virginia has been mapped. These publications have been of great use in the preparation of the present work.

The Cambrian and Ordovician formations only are described at this point, so that in order to present the complete stratigraphic column of southwestern Virginia, figures 16 and 17 are introduced. The columnar section of the post-Ordovician formation shown in figure 16 may be regarded as typical for the northern half of this area, while in figure 17 the same interval in the southern half is represented. In each of these tables, as well as in figure 2 on page 43, it will be noted that following the usage of the U. S. Geological Survey at that time, the term Silurian includes both Ordovician and Silurian as now understood.

[a] Proc. Amer. Phil. Soc., Vols. XIX, XXII, and XXIV.

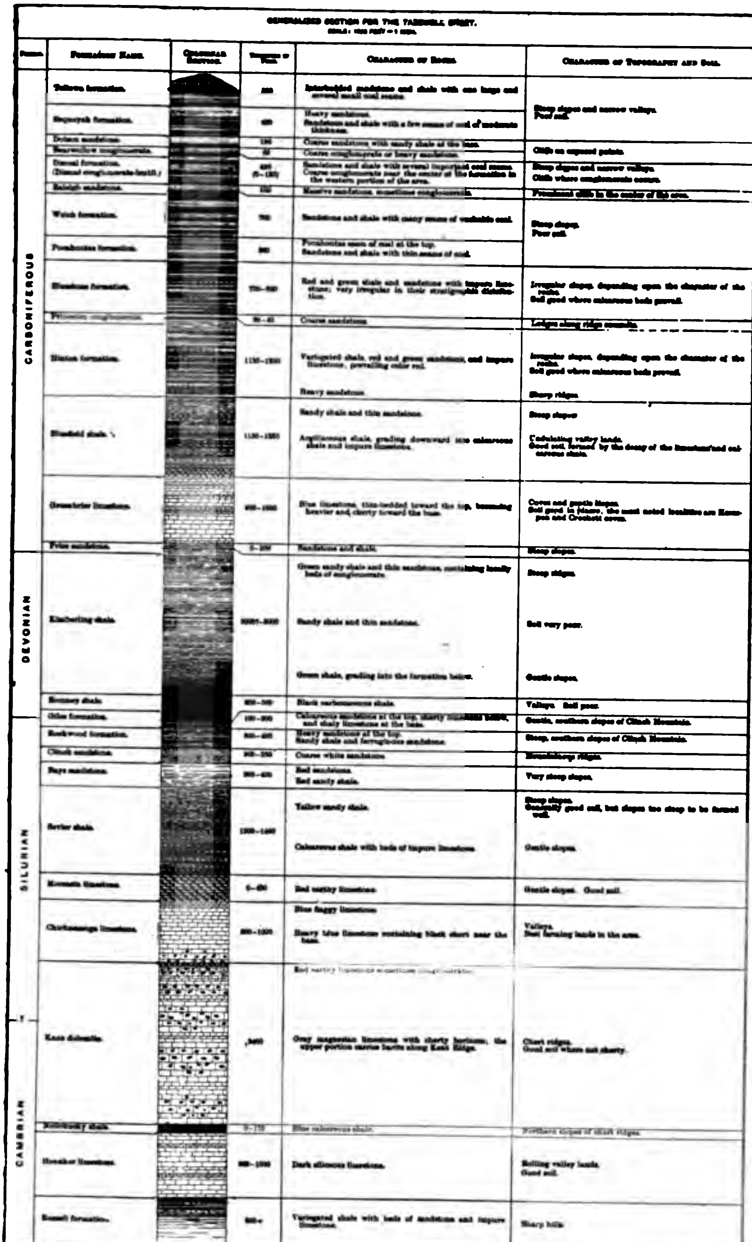


Fig. 16.—Generalized section of the area covered by the Tazewell folio, U. S. Geol. Survey. (After M. R. Campbell.)

In the discussions of central western or of northwestern Virginia, the writer has indicated no great difference in the stratigraphic succession or lithology of the Ordovician strata in various parts of the Valley, although the several divisions that have been instituted are described. In southwestern Virginia, however, a new factor in the study of these same strata is introduced. Ordinarily rocks deposited synchronously in comparatively small areas show no great differences either in lithological aspect or in their fossil contents. In the division of the state under discussion, however, the Ordovician strata, particularly, differ in various areas in both of these respects. For example, the eastern portion of the great Valley shows a development of Ordovician limestones and shales totally different from rocks occupying the same stratigraphic interval in the westernmost part of the state. In the study of the various sections, these differences in strata of the same age were encountered in traverses made across the Valley and ridges to the west, while little difficulty was experienced in correlating the rocks in directions paralleling the length of the Valley.

MAJOR FAULTS.

When compared with the two divisions discussed previously, the geology of southwestern Virginia is complicated by great folds and overthrust faults. The region is traversed along a northeast-southwest line by at least seven major faults and a number of minor breaks. The easternmost of these major faults passes along the base of the Holston and Iron mountains where a sandstone of Lower Cambrian age is faulted against the dolomitic limestones. Sandstone, shales, and impure limestone outcrop east of this fault, but on account of their unsuitable chemical composition are not considered here.

The six major faults west of this eastern break have been described and named by Professors Lesley and Stevenson in the articles mentioned in the Bibliography, page 297. These are, in regular order going westward, (1) the Walker mountain, (2) Saltville, (3) Copper creek, (4) Hunter Valley, (5) Wallen Valley, and (6) Poor Valley faults. Inasmuch as these faults outline the areas of similar strata, they are briefly described below. These seven major faults, as a glance at the accompanying map and structure section will show, divided southwestern Virginia into six rather narrow areas, in each of which a belt of Ordovician limestones and shales is usually exposed. (See figures 18 and 19.)

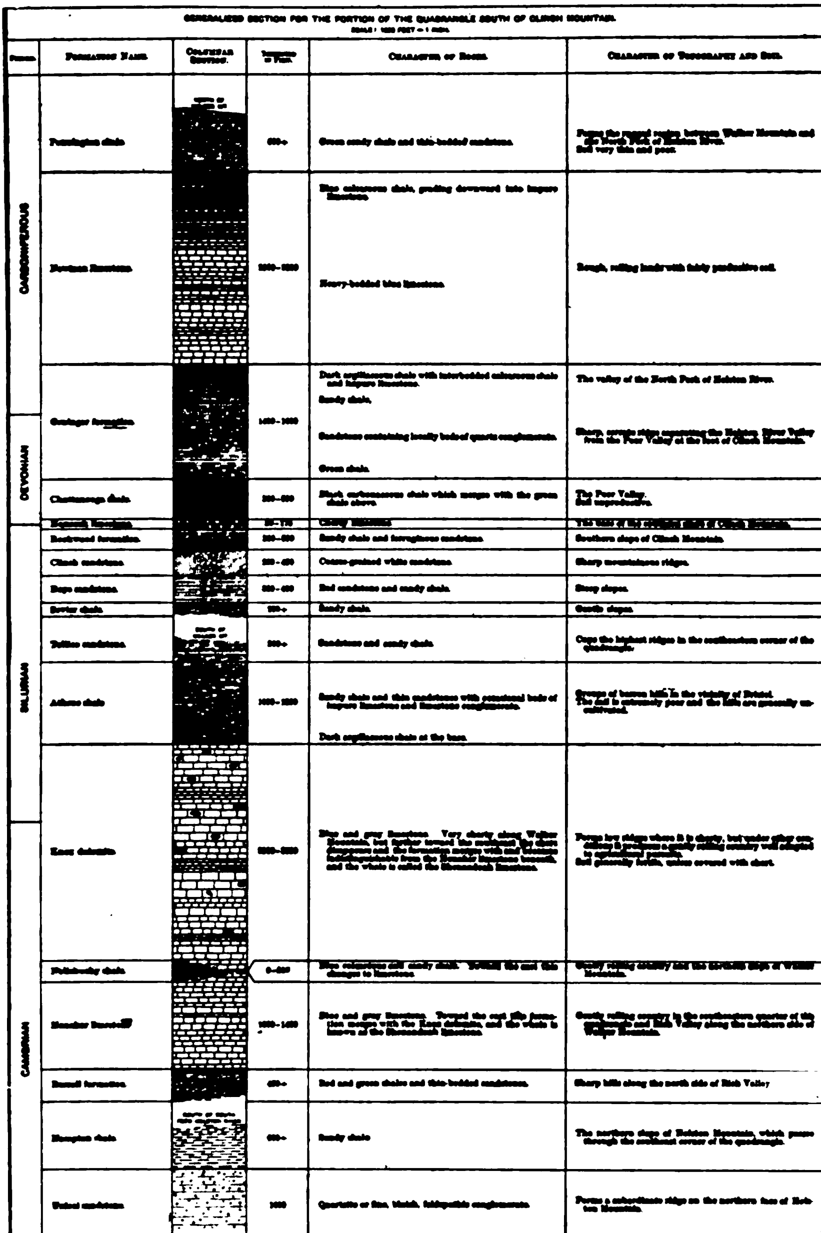


Fig. 17.—Generalized section for the portion of the area south of Clinch mountain covered by the Bristol folio, U. S. Geol. Survey. (After M. R. Campbell.)

Walker mountain fault.—The western part of the Valley of Virginia in this part of the state is traversed by a fault which has been named as above by Professor Stevenson on account of its development along the southerly base of Walker mountain. This fault enters the state just west of Bristol where the displacement is comparatively slight. Continuing northeast the displacement increases until in Smyth county east of Walker mountain, Cambrian limestones are brought into contact with Carboniferous strata. About two miles west of Glade Spring along the Saltville branch of the Norfolk and Western railroad, this fault is crossed and the general relations are fairly well shown. Continuing westward along this railroad the geologic succession is normal until at Saltville the Cambrian limestones are again found thrust upon Carboniferous rocks. This, the Saltville fault, marks the second great break.

Saltville fault.—This structural line can be followed from its typical locality at Saltville southwestward through Virginia, Tennessee, and into Georgia, where the name Rome fault has been applied to it by Hayes.[a] This fault has a considerable extension northeastwardly in Virginia, so that altogether it is one of the best developed and most persistent structural features of the state. The amount of displacement likewise is great, being usually between the Carboniferous and the Cambrian. The Saltville fault follows the western slope of Walker mountain throughout Washington and Smyth counties in Virginia, paralleling the fault previously described. The strip of country bounded by the two is usually about four miles in width. Continuing westward or northwestward from this fault, the geologic formations are exposed in descending order until in the Copper Creek valley a third fault, involving the Cambrian limestone, is encountered.

Copper Creek fault.—Although this is one of the most persistent faults, the average amount of displacement is less than any of the other major faults. The strata involved are of Cambrian and Ordovician age, the usual faulting being between the limestones of the Middle Cambrian and those of the Middle Ordovician. This fault is of importance in the present connection since it repeats the Ordovician limestone and thus adds a strip of cement-making rocks to the several counties crossed. The Copper creek fault is well exposed along the Virginia and Southwestern railroad just north of Speer Ferry, where Cambrian and Middle Ordovician limestones may be observed in contact.

[a]Bull. Geol. Soc. Amer., 1892, Vol. II, p. 144.

Hunter Valley fault.—Proceeding north along the same railroad the last of the more extended faults may be noted. This marks the eastern edge of the principal coal field of southwestern Virginia with the Cambrian limestone on the upthrow side to the east. Hunter valley in Scott county is traversed by this fault, whence its name given by Professor Stevenson. The extreme southwestern portion of the state is occupied by rocks older than the Coal Measures, and here the fault is between the Cambrian and Silurian or Devonian strata.

Wallen Valley fault.—The fifth and sixth of these major faults are of much less extent in Virginia than those previously described, as they are developed practically only in Lee and Wise counties. Both enter the state from Tennessee and proceed but a short distance beyond the eastern boundary of Lee county. In Virginia the eastern fault of the two begins at the head of Wallen valley and continues southwardly along the southern side of Wallen ridge.

Poor Valley fault.—This fault has its origin in a gentle anticline near Little Stone Gap, in Wise county. Southwestward this anticline becomes steeper, breaks, and the fault develops. The effect of this in Lee county is to expose two strips of the Ordovician limestones and shales, thus adding to the economic resources of the county.

GENERAL DISTRIBUTION OF CAMBRIAN AND ORDOVICIAN STRATA.

As stated on a previous page, the study of numerous sections including the Ordovician rocks in this part of the state brought out the fact that similar successions of these strata are at present exposed in long narrow areas bounded by the major faults. The differences in sedimentation of these various areas may perhaps most readily be shown by an outline of the stratigraphic succession in each. In both cases the well known Knox dolomite serves as a basal datum line and the identification of the various formations rests upon their fossil contents as well as their lithologic characters.

In the easternmost area, namely the region between the Blue Ridge and the Walker mountain fault, the following succession of Ordovician rocks may be observed:

3. Thin-bedded sandstones and sandy shales (Tellico).
2. Blue to black calcareous and sandy shales (Athens).
1. Knox dolomite.

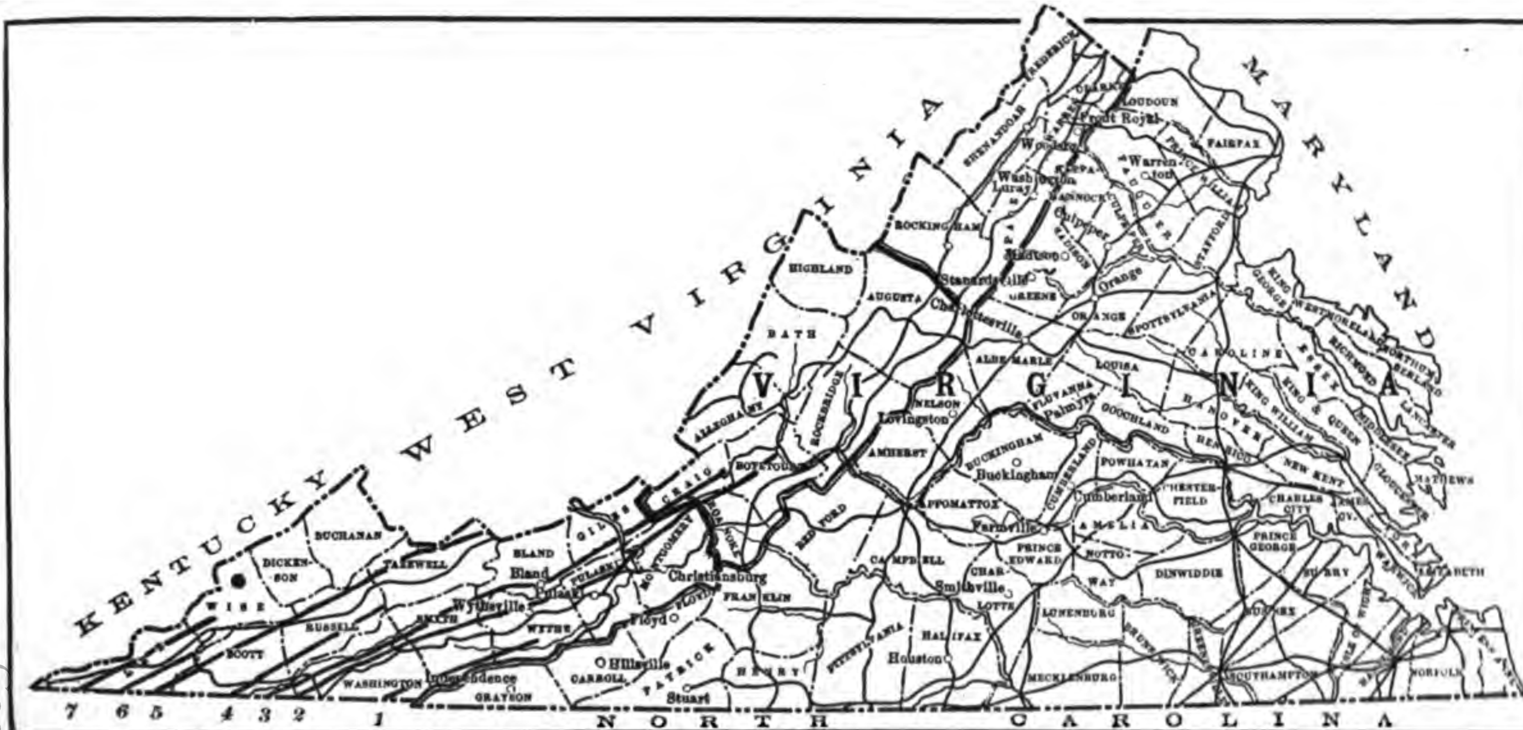


Fig. 18.—Map showing three divisions of the western part of state, and the major faults of southwest Virginia. The fault numbers correspond to the same in the accompanying structure section across the southwestern part of the state.

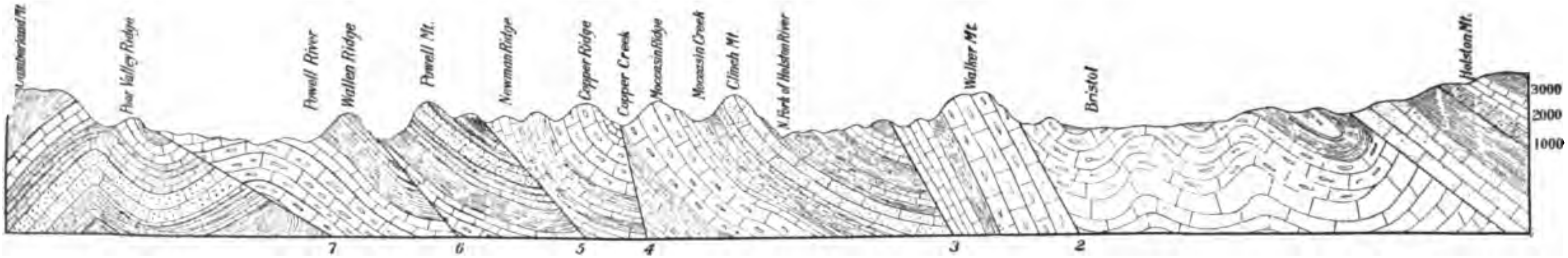


Fig. 19.—Structure section across southwest Virginia from Holston mountain west to Cumberland mountain. This section illustrates the blocks into which southwest Virginia is divided by the major faults of the region. The length of the section has been greatly lessened and the height exaggerated. As a result, only the general geologic structure of each block could be shown. 1. Fault along western edge of Holston mountain; 2. Walker Mountain fault; 3. Saltville fault; 4. Copper Creek fault; 5. Hunter Valley fault; 6. Wallen Valley fault; 7. Poor Valley fault.

Locally a thin siliceous blue limestone, the equivalent of the Lenoir limestone of eastern Tennessee, and a thin dove limestone of Stones River age, occur between the Knox and the Athens.

The narrow strip between the Walker mountain fault and the Saltville fault shows an overlapping of the formations of the next western band upon sediments of the one just described. This section, which is most clearly shown along the railroad from Glade Spring to Saltville, is as follows:

7. Red sandy shales and thin-bedded sandstone (Bays).
6. Yellow and dark-colored shales with thin-bedded blue limestone at base (Sevier).
5. Red calcareous shales and impure red limestone (Moccasin).
4. Beds of marble with calcareous shales (Holston).
3. Blue and black calcareous shales (Athens).
2. Thick-bedded, gray magnesian and dove limestone (Stones River).
1. Knox dolomite.

Beds of marble known as the Holston marble associated with thin limestones and shales holding the same fauna immediately follow the Knox dolomite in the next area, namely the region between the Saltville and Copper creek faults. Here, with the exception that the Stones River limestone and Athens shale are wanting, the section, as shown below, is essentially the same as the preceding one:

6. Heavily bedded white quartzite and sandstone (Clinch).
5. Red sandy shales and thin-bedded sandstone (Bays).
4. Yellow and dark-colored shales with thin-bedded blue limestone at the base (Sevier).
3. Red calcareous shales and impure red limestone (Moccasin).
2. Marble at base followed by thin-bedded limestone and shales (Holston marble and associated strata).
1. Knox dolomite.

The Holston marbles are particularly well developed in Tennessee. In Virginia the northernmost occurrence of the fauna associated with these marbles was noted at the foot of Clinch mountain, south of Tazewell.

The strip bounded by the Copper creek and Hunter valley faults contains the Knox dolomite, Holston, Moccasin, Sevier, Bays, and Clinch formations, in the most southern part of the state, but in the northern portion of southwest Virginia in place of the marbles and thin-bedded limestones of the Holston, heavily bedded, gray and dark blue limestone is found.

The exact equivalents of this massive limestone have not yet been determined, and in the "Mineral Resources of Virginia" (page 137) the provisional new name, Pearisburg limestone, was employed.

The westernmost and most different sequence of the Ordovician in Virginia is found west of the Hunter valley fault, particularly in the valley of Powell river. Here the arrangement of the rocks, with the exception of the Clinch sandstone, is exactly the same as that obtaining in southwestern Ohio, central Kentucky, and central Tennessee. In Virginia these rocks are known to occur throughout the Powell river valley eastward to the Wallen valley fault, and more recent investigations have shown that the narrow strip between this fault and that of Hunter valley is also occupied by them. The formational names noted below for this section are those used by the U. S. Geological Survey for mapping purposes, but the equivalent in the Ohio valley Ordovician are given in parentheses:

Clinch sandstone, heavy bedded white quartzite or sandstone.
Bays sandstone, red and yellow limestones and shales (Lorraine).
Sevier shale, olive and yellow shales and thin limestones (Eden).
Chickamauga limestone.
- Thin-bedded blue limestones and shales (Trenton-Cathey).
- Dark blue crystalline limestone (Trenton-Bigby).
- Yellow and olive shales (Trenton-Hermitage).
- Thin-bedded dove limestones and yellow shales (Tyrone).
- Massive Dove limestone (Stones River).

Knox dolomite.
- Massive magnesian limestone.

On account of the variation of the rocks, particularly of the Ordovician strata, in these different areas, the importance, from an economic standpoint, of delimiting their boundaries, is apparent.

The theories for this distribution of strata in separate areas need not be entered upon here more than to state that Ulrich and Schuchert, in their "Paleozoic Seas and Barriers," have advanced the apparently well founded idea that the area of the Appalachian Valley during Ordovician times was divided longitudinally into several narrow troughs which were more or less effectively separated from each other; and that the observed differences in sedimentation and life characterizing the several troughs are attributable to this separation.

The general relation of the Cambrian and Ordovician formations and

the more important cement rock horizons are indicated in the following correlation table:

Cambrian and Ordovician formations of southwest Virginia.

General time scale.	Bristol area.	Walker Mt. area.	Clinch Mt. area.	Copper Creek area.	Powell Valley area.
Upper Ordovician		Clinch Bays Sevier[a]	Clinch Bays Sevier[a]	Clinch Bays Sevier[a]	Clinch Bays (Lorraine) Sevier[a] (Eden)
Middle Ordovician	Tellico Athens[a] Stones River (often absent)[a]	Moccasin Holston[a] Athens[a] Stones River[a]	Moccasin Holston[a] and associat'd strata[a]	Moccasin Chickamauga	Chickamauga (Trenton)[a] (Tyrone)[a] (Stones River)[a]
Lower Ordovician Saratogan (Upper Cambrian)	Knox	Knox	Knox	Knox	Knox
Acadian (Middle Cambrian)	Nolichucky Honaker	Nolichucky Honaker	Nolichucky Maryville Rogersville Rutledge	Nolichucky Maryville Rogersville Rutledge	
Georgian (Lower Cambrian)			Russell	Russell	

[a]Important horizons of cement materials.

STRATIGRAPHY.

In the following discussion of the stratigraphy of southwestern Virginia, the several areas of Ordovician strata are considered separately, while the Cambrian formation, being of more uniform distribution and of less value economically, are treated less in detail. For convenience of reference and for the sake of completeness, analyses of materials from the various formations are quoted here in tabular form.

Cambrian Formations.

Strata of Lower and Middle Cambrian age in southwestern Virginia may be roughly classified lithologically into two groups: (1) a lower arenaceous group including the Unicoi, Hampton, and Russell formations,

and (2) an upper argillaceous, calcareous portion embracing the Rutledge limestone, Rogersville shale, Maryville limestone, and Nolichucky shale. From a paleontological standpoint these two main divisions correspond in a general way to the Lower Cambrian and Middle Cambrian respectively. Of these several formations the upper part of the Rogersville shale, the Maryville limestone, and the Nolichucky shale are worthy of consideration as possible sources of supply for cement materials.

Unicoi sandstone.—The oldest sedimentary formation in this area so far described is a heavy bed of sandstone or quartzite with an exposed thickness of 1,000 feet to which Mr. M. R. Campbell[a] applied the above name. On the western side of its outcrop the formation is bounded by a fault so that the total thickness has not been determined. However, as the Unicoi is in all probability the northern extension of the lower member of the Chilhowee sandstone of Tennessee, with a thickness of 2,000 feet, the minimum thickness of 1,000 feet for the former is not far from the truth. The main outcrops of this standstone are along the base of the Holston and Iron mountains.

Hampton shale.—Overlying the Unicoi sandstone is a bed of sandy shale with a thickness of about 600 feet. This is the extension into Virginia of the shaly portion of the Chilhowee sandstone of Tennessee and the formation outcrops mainly along the Holston and Iron mountains.

Succeeding the Hampton shale is another bed of sandstone, and above this is a series of beds of shales and limestones about 3,000 feet thick in all. These have not received detailed study or names. The entire series, however, is known to be of Lower Cambrian age and is probably to be correlated with rocks of like age on the western side of the Valley.

Russell formation.—The oldest strata outcropping in southwestern Virginia northwest of Holston mountain are sandy shales, thin-bedded sandstones and brown argillaceous shales, found in the valleys of Copper creek and Clinch river.

The formation as a whole is known to be 1,000 or more feet in thickness and is easily distinguishable by its lithologic character, as well as by the topography to which it gives rise. The sandy beds upon weathering form sharp ridges which are in marked contrast to the low knobs about them. These sandy beds make up the greater part of the formation, but the brown argillaceous shales occur in the upper portion and vary from 200 to 600 feet in thickness. North of Clinch river the maximum thickness of these shales is reached, while south of this river the thickness greatly diminishes.

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[a] U. S. Geol. Surv., Folio 59, 1899.

The Russell formation contains the Olenellus fauna, and is therefore of Lower Cambrian age.

Although the major portion of the formation is of little value from an economic standpoint, the argillaceous shales of the upper division may prove of use for mixture with pure limestones in the manufacture of cement. The great range in the chemical composition of these shales, indicated in the following analyses, would lessen their possible value in this respect:

Analyses of Russell shales, vicinity of Clinchport, Va.

(J. H. Gibboney, Analyst.)

	I.	II.
	Per cent.	Per cent.
Insoluble	41.72	89.52
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	5.68	7.22
Lime (CaO)	17.32	0.40
Calcium carbonate ($CaCO_3$)	30.93	0.72
Magnesia (MgO)	9.17	1.05
Magnesium carbonate ($MgCO_3$)	19.29	2.21
Total	97.59	101.12

I. Brown argillaceous shales, upper part of formation.
II. Sandy shales, several hundred feet from top of formation.

Rutledge limestone.—The argillaceous shale division of the Russell formation is followed by 200 to 300 feet of limestone which, on account of good exposures at Rutledge, Grainger county, Tennessee, takes its name. The lower portion contains many thin beds of sandy shale while the upper portion is a dark, impure, magnesian limestone. The composition of this limestone varies considerably, but the magnesia content appears too high in all the samples examined to make the rocks of use.

Analyses of Rutledge limestones, vicinity of Clinchport, Va.

(J. H. Gibboney, Analyst.)

	I.	II.
	Per cent.	Per cent.
Insoluble	3.88	2.58
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	1.36	1.12
Lime (CaO)	46.22	30.80
Calcium carbonate ($CaCO_3$)	82.53	55.00
Magnesia (MgO)	5.62	19.70
Magnesium carbonate ($MgCO_3$)	11.80	41.37
Total	99.57	99.97

I. Gray limestone near base of formation.
II. Dark limestone near top of formation.

Rogersville shale.—Separating the impure Rutledge limestone from the pure limestone of the succeeding formation—the Maryville limestone—is a blue to brown somewhat calcareous shale well developed at Rogersville, Tenn. This formation is abundantly fossiliferous and contains a fauna of Middle Cambrian age. The shales persist as such over a considerable area in northeastern Tennessee, and in southwestern Virginia, but in the latter region it disappears as a shale formation toward the east. Along the western side of the Valley the Rogersville shale often changes to a dark siliceous limestone which cannot be separated from the underlying Rutledge limestone. The siliceous nature of the lower part, and the higher lime content of the upper beds, is indicated in the analyses:

Analyses of Rogersville shale, vicinity of Clinchport, Va.

(J. H. Gibboney, Analyst.)

	I.	II.
	Per cent.	Per cent.
Insoluble	31.22	87.48
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3) }	6.20	1.32
Lime (CaO)	21.41	3.60
Calcium carbonate ($CaCO_3$)	38.23	6.42
Magnesia (MgO)	10.90	1.76
Magnesium carbonate ($MgCO_3$)	22.89	3.70
Total	98.54	98.92

I. Calcareous shales, upper part of formation.
II. Sandy shales, lower part of formation.

Maryville limestone.—Of all the Cambrian formations, this is the most promising from an economic standpoint, because it is often a comparatively pure limestone which, in combination with associated shales, might make a good cement rock mixture. Wherever these strata occur as a well defined formation, they are heavily bedded, blue limestones, varying in thickness from 500 to 650 feet. The type locality is at Maryville, Blount county, Tennessee, but typical exposures are found in southwestern Virginia northwest of a line following Moccasin ridge.

The greater part of the Maryville limestone has a mottled laminar appearance, which, especially when weathered, makes its recognition in the field comparatively easy. This peculiar aspect of the rock seems to be due to the alternate deposition of thin bands of material differing slightly in color and solubility. Upon weathering, the less soluble material stands out in thin, irregularly parallel ridges. In fresh exposures the difference

in color gives the mottled aspect. The Middle Ordovician Lenoir limestone of the areas east of Clinch mountain resemble the Maryville so greatly that without fossils considerable difficulty in separating them would be experienced.

The characteristic fossil of the Maryville limestone in Virginia is a branching fucoid one-fourth of an inch in diameter with a core one-half as thick. Some of the layers are crowded with these obscure organisms.

The various beds making up the Maryville limestone are well shown in a section near Clinchport:

Section of Maryville limestone along Virginia and Southwestern railroad, just south of Clinchport, Va.

	Thickness in feet.
Nolichucky shale:	
Greenish or olive shales	550
Maryville limestone:	
(d) Shales and thin limestones interbedded	50
(c) Mottled laminar fine-grained limestones with a few massive granular layers	90
(b) Massive dark gray dolomite with a few dark cherty layers	50
(a) Fine-grained, mottled bluish limestone rather low in magnesia	300
Rogersville shale:	
Blue slightly calcareous shale	—

Samples for analysis were selected from the rocks in the above section with the following results:

Analyses of Maryville limestone, vicinity of Clinchport, Va.

(J. H. Gibboney, Analyst.)

	I.	II.	III.	IV.
	Per cent.	Per cent.	Per cent.	Per cent.
Insoluble	35.06	31.78	10.54	2.16
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3) }	1.90	1.84	0.64	0.54
Lime (CaO)	29.16	35.78	46.74	50.80
Calcium carbonate ($CaCO_3$)	52.07	63.89	83.43	89.43
Magnesia (MgO)	5.33	0.93	1.82	3.79
Magnesium carbonate ($MgCO_3$)	11.20	1.96	3.82	7.95
Total	100.23	99.47	98.43	100.08

I and II. Cherty black limestone (bed *b* of section).
III. Blue crystalline limestone (bed *a* of section).
IV. Grayish, subcrystalline limestone (bed *c* of section).

Honaker limestone.—Southeast of a line paralleling Moccasin ridge, the Maryville limestone, the Rogersville shale, and the Rutledge limestone, cannot be distinguished as separate formations, but form a lithological unit for which the name Honaker limestone is employed, because of good exposures at Honaker, Russell county, Virginia. This formation is of blue and gray limestone with a maximum thickness of 1,400 feet. It seems worthy of exploration only as a source of natural cement rock.

Nolichucky shale.—This formation, the second shale horizon of any economic importance, overlies the Honaker limestone in the Valley proper but succeeds the Maryville limestone west of Moccasin ridge. The shale derives its name from the Nolichucky river in Tennessee, where it carries a fauna of Middle Cambrian age. As a whole the formation is composed of calcareous greenish to olive shale and shaly limestone reaching a maximum of 400 feet in thickness. West of Copper ridge the Nolichucky shale is greatest in thickness, but eastward it diminishes, until just east of Bristol it disappears altogether. At a few localities in southwestern Virginia, the Nolichucky shale contains limestone lentils of considerable thickness, which, with the associated shales, furnish an abundance of raw material for cement manufacture. The most important of such occurrences is in Carter valley, where a lentil of blue limestone with a maximum thickness of 500 feet is found. The one sample collected for analysis was apparently an average fragment of the unweathered shale.

Analysis of Nolichucky shale, vicinity of Clinchport, Va.

(J. H. Gibboney, Analyst.)

	Per cent.
Insoluble	38.68
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3) }	5.28
Lime (CaO)	29.46
Calcium carbonate ($CaCO_3$)	52.61
Magnesia (MgO)	0.80
Magnesium carbonate ($MgCO_3$)	1.69
Total	98.26

Cambro-Ordovician.

Knox dolomite.—Succeeding the Nolichucky shale is the great limestone formation of the Valley—the Knox dolomite. In the portion of Virginia under discussion, this formation varies from 2,000 to 3,000 feet in thickness, a considerable diminution from the 4,000 or more feet exposed in the typical localities in Knox county, Tennessee. The Knox is generally

a heavily bedded gray magnesian limestone or dolomite with comparatively few natural outcrops. The line of outcrop is usually indicated by a heavy mantle of residual chert. It has been noted that at some places in southwestern Virginia the top of the formation is defined by a white argillaceous limestone which, if developed in sufficient quantity, and easily accessible, might prove of value economically. Otherwise the Knox as a whole cannot be considered of much economic interest in the present connection. Some of its strata are of suitable composition for both cement and lime purposes, but the Ordovician limestones are so vastly superior that it would be useless to employ the Knox limestone except possibly for local lime burning.

The Knox dolomite is one of the sources of the ridges of southwestern Virginia, but only when its strata are inclined at a considerable angle. In the process of weathering, the soluble dolomite is washed away, leaving the insoluble chert to maintain the ridge. In this area the most prominent of such ridges are Copper and Moccasin ridges, Walker mountain, and Chestnut ridge. On these Knox ridges the chert is usually confined to the southeastern slope since the lower more cherty blue limestone mentioned below outcrops ordinarily on the southwestern side. When the strata are horizontal, or nearly so, and the chert-bearing beds are exposed at the surface, low knobs instead of ridges are developed.

The lower part of the formation is generally unfossiliferous, but from evidence found elsewhere in the Valley, this portion is of Upper Cambrian age. The cherts in the upper and middle parts of the Knox dolomite are sometimes fossiliferous and contain faunas of earliest Ordovician and Beekmantown ages, respectively.

Up to the present time, no attempt has been made to recognize any definite subdivisions in the Knox in Virginia, and these strata have been described and mapped simply as a great dolomite formation giving rise to abundant chert upon weathering. The comparative scarcity of natural outcrops of the rock itself has caused this chert often to be relied upon entirely in mapping. Areas showing little chert have not been differentiated upon the maps. When it is realized that these cherty and non-cherty areas contain soils of widely different fertility, the desirability of distinguishing the limestones giving rise to each is obvious.

As long ago as 1869 Prof. J. M. Safford indicated four divisions of the Knox dolomite in his type section in the vicinity of Knoxville, Tenn.

Fig. 1.—View, natural size, of a chert fragment from the middle Knox, near Speer Ferry, Va. The dense, solid material and the style of fracture are characteristic.

Fig. 2.—A fragment of sandy chert, × 2, from the upper Knox, near Bristol, Va. These residual cherts are each characteristic of the divisions mentioned, and aid in the identification of the strata.

CHERTS FROM THE KNOX DOLOMITE.

Subsequent students have apparently paid little attention to these divisions, but recent work in the Appalachian Valley by Dr. E. O. Ulrich and the writer indicates that Professor Safford's divisions are not only valuable and necessary in detailed stratigraphic work, but also can be correlated directly with known formations of the general time scale. For comparison with Virginia sections, Professor Safford's description[a] of these beds is given below:

Section of Knox dolomite, Knoxville, Tenn., and vicinity.

	Feet.
(d) Dolomite and limestone, mostly light gray sparry dolomite, with more or less chert throughout; upper part interstratified with blue layers which are fossiliferous; thickness	980
(c) Chert	4
(b) Dolomite, mostly dark gray and sparry, heavy-bedded; contains more or less chert throughout, some of which approaches sandstone; upper part includes gray dolomite; thickness	1,870
(a) Limestone and dolomite, mostly blue, but some of the upper strata dark gray and sparry; the blue is partly compact and partly oölitic; the lower part is interstratified with shale, thus running into the shale division below; fossiliferous; entire thickness	650
Entire thickness	3,504

Upon combining b and c of the above section, the typical Knox dolomite is seen to consist of (1) a lower non-cherty division of mainly blue, compact limestone and dolomite, (2) a thicker middle division of dark gray, heavy-bedded dolomite with more or less chert, and (3) an upper division of interbedded light gray and blue layers, with more or less chert. A reëxamination of this section has shown that the middle division gives rise to an abundance of solid, angular, flinty chert, and that the chert of the upper division is of a porous, sandy nature. Indeed, the best criterion in distinguishing these two divisions is the different aspect of their cherts. Specimens of these cherts from Virginia localities are illustrated on plate XVII.

Continuous, well exposed sections of the Knox dolomite are rare. In southwestern Virginia, probably the best, as far as exposures are concerned, may be seen along the Virginia and Southwestern railroad between Clinchport and Speer Ferry. The detailed stratigraphy of this region is illustrated in the structure section on page 226, where the arrangement of the Knox beds in the band nearest Clinchport is as follows:

[a] Geology of Tennessee, 1869, p. 205.

Section of Knox dolomite along the Virginia and Southwestern railroad, just south of Clinchport, Va.

	Feet.
Upper Knox (Beekmantown)	400+
Fine-grained, rather thin-bedded limestone, rather low in magnesia and varying in color from light yellowish gray to purple and green. Some of the layers are mottled and others contain a small amount of shale. These strata weather into a deep red soil holding a comparatively small amount of sandy, porous, soft chert easily disintegrating into sand.	
Middle Knox (earliest Ordovician), about	1,100
Light to dark gray, highly magnesian, usually fine-grained limestone weathering into a yellow or yellowish red soil full of solid, angular, flinty chert. The lowest beds (100 feet or less in thickness) are of sandstones or sandy and oölitic dolomites.	
Lower Knox (Upper Cambrian)	500
Massive non-cherty limestone and dolomite, mostly dark gray dolomite, but a few layers are of pure blue limestone while others are of a yellowish gray color and low in magnesia. *Cryptozoon proliferum* the only fossil noted.	

The section nearest Speer Ferry exposes some of the Knox strata to better advantage than that in the Clinchport area, and for this reason is given below:

Section of Knox dolomite, vicinity of Speer Ferry, Va.

	Feet.
Upper Knox (Beekmantown), about	600
Bluish gray to yellowish and sometimes nearly white magnesian and argillaceous fine-grained limestone with a few pinkish layers. Chert scarce, a layer one foot in thickness occurring about the middle of the division representing the only distinct bed seen.	
Middle Knox (Earliest Ordovician), about	1,100
600 feet granular and fine-grained massive gray dolomite.	
400 feet less massive, coarsely laminated dolomite, bluish gray to brownish in color.	
100 feet thin-bedded, laminar, earthy, blue-gray magnesian limestone with beds of nearly white dolomite separated by sandy seams at the base.	
All of these Middle Knox strata give rise to abundant chert when weathered, although little or no chert may be seen in fresh cuts.	
Lower Knox (Upper Cambrian), about	500
180 feet massive, dark gray, fine-granular, non-cherty dolomite. These strata give a hackly fracture, are irregularly bedded in the lower part and are sometimes brecciated.	
190 feet light and dark gray dolomite without chert, in beds varying from four inches to four feet in thickness.	
130 feet light gray dolomite with little or no chert.	

Lower Knox.—As noted before, little of the Knox limestone is suitable as a cement material directly, although the purer limestone of the lower division might be used in mixture with shaly material. The expense of separating these purer strata from the associated dolomitic rock would in most cases prevent its use in any way, except locally, for the burning of lime. The high percentage of calcium carbonate in some of these strata

Fig. 1.—A fragment of banded chert, natural size, introduced for comparison with the fossil organism *Cryptozoön*. These banded cherts differ in that their layers are evenly and uniformly developed. Side views of the *Cryptozoön* show a more or less columnar structure. Middle Knox, Virginia and Southwestern railroad, near Speer Ferry, Va.

ide view of a fragment of *Cryptozoön proliferum*, natural size, from the Knox, near Speer Ferry, Va.

is indicated in the following analyses. Still, much of the rock of this division averages as high in magnesia as the succeeding Knox strata, and the absence of chert is probably the surest way of separating these strata from the associated dolomite where stratigraphic means are not available. Some of these Lower Knox strata contain an abundance of a peculiar fossil known as *Cryptozoon proliferum,* of which a Virginia example is figured on plate XVIII.

Analyses of Lower Knox limestone.

(J. H. Gibboney, Analyst.)

	I.	II.
	Per cent.	Per cent.
Insoluble	2.54	9.60
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	0.78	0.40
Lime (CaO)	53.90	50.60
Calcium carbonate ($CaCO_3$)	96.25	90.35
Magnesia (MgO)	0.41	4.29
Magnesium carbonate ($MgCO_3$)	0.87	9.00
Total	100.44	110.35

I. Purer limestone seam from thick-bedded strata, 2 miles south of Saltville, Virginia.
II. Bluish-gray limestone, vicinity of Clinchport, Va.

Middle Knox.—The abundant and characteristic chert fragments left by the weathering of this division causes it to be easily recognized. These cherts occur usually as solid, angular or nodular light yellowish to red hard, flinty masses sometimes reaching a diameter of several feet. Upon long exposure to the atmosphere these large masses break up into small block-like pieces with a hackly or obscurely conchoidal fracture. These, unlike the cherts of the Upper Knox, are broken with some difficulty, a sharp blow of the hammer being required. Some of these chert masses show a banded structure (see figure 1, plate XVIII) closely simulating the fossil *Cryptozoon.*

A field or hillside covered with these large and small angular flint-like rocks is so characteristic of the Middle Knox that little difficulty is experienced in identifying the horizon. Indeed these particular cherts have been observed so frequently that they have been erroneously regarded as characteristic of the Knox dolomite as a whole. A few of the chert layers afford numerous fossils, mainly coiled gastropods. A fragment of this fossiliferous chert is figured on plate XX.

Because of the prevailing dolomitic character, no samples of the Middle Knox were selected for analysis.

Upper Knox.—More attention was paid to this division of the Knox in Virginia since in all probability its strata will prove of more value than the purer limestones of the lower divisions, and, again, larger areas are underlaid by it. East of the Walker mountain fault this seems to be the prevailing surface rock over much of southwestern Virginia, while west of this line the more productive areas are located on it. For these reasons more numerous samples were therefore selected for analysis, and the range in composition is well shown in the tables given below:

Analyses of Knox dolomite.

(J. H. Gibboney, Analyst.)

	I.	II.	III.	IV.	V.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Insoluble	24.54	3.98	3.62	1.40	40.44
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	3.66	1.12	0.48	0.08	4.00
Lime (CaO)	39.20	44.88	37.90	31.48	16.90
Calcium carbonate ($CaCO_3$)	70.00	80.14	67.68	56.22	30.18
Magnesia (MgO)	0.62	6.43	13.50	20.29	11.42
Magnesium carbonate ($MgCO_3$)	1.31	13.52	28.35	42.61	23.98
Total	99.51	98.76	100.13	100.31	98.61

	VI.	VII.	VIII.	IX.	X.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Insoluble	1.38	7.56	8.09	34.62	12.34
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	2.88	0.98	1.52	4.72	2.34
Lime (CaO)	52.48	30.10	46.64	31.72	39.60
Calcium carbonate ($CaCO_3$)	93.71	58.75	83.28	56.64	70.72
Magnesia (MgO)	0.67	18.00	3.18	1.26	6.22
Magnesium carbonate ($MgCO_3$)	1.41	37.80	6.68	2.64	13.06
Total	99.38	105.09	99.57	98.62	98.46

I. Arenaceous limestone, 800 feet below top of formation, near Goodwin Ferry, Giles county.
II. Dolomite limestone, lower portion of Beekmantown formation, 4 miles south of Saltville, Va.
III. Dolomite limestone, upper part of Beekmantown formation, 4 miles south of Saltville, Va.
IV. Knox dolomite, Lyon Gap section (bed 1), Smyth county.
V. Knox dolomite, Lyon Gap section (bed 2), Smyth county.
VI. Dove-colored purer limestone, near Goodwin Ferry, Giles county.
VII. Gray dolomite limestone, upper part of formation, vicinity of Clinchport, Va.
VIII. Less dolomitic layer in upper part of formation, vicinity of Clinchport, Va.
IX and X. White argillaceous limestone, top of formation, Speer Ferry, Va.

Fig. 1.—View of massive conglomeratic limestone supposed to represent a reef at the beginning of upper Knox (Beekmantown) time. Railroad cut one-half mile northwest of station at Narrows, Va. View shows upper portion of reef with overlapping, even-bedded upper Knox strata.

Fig. 2.—Nearer view of reef.

REEF IN BEEKMANTOWN LIMESTONE.

The sections given on pages 153 and 154 indicate that the upper or Beekmantown portion of the Knox is made up of thin-bedded strata, usually lower in magnesia than the other divisions. Fossils are probably most abundant in this division, although, as elsewhere in the Knox, the best specimens occur with the cherts. The long, slender shell, *Hormotoma artemesia* (see plate XX), has been found at a number of Virginia localities, but usually as internal casts. A second, rather abundant gastropod is the flat, coiled shell, *Maclurea oceana,* but most abundant and characteristic of all is a horn-like fossil (plate XX, figure 3) referred to as the operculum of an unknown shell.

Near or at the base of the Upper Knox are large, more or less contorted bodies of limestone showing no bedding planes, but included between well marked, stratified rocks. These bodies are of massive, conglomeratic limestone, while the strata above and below are of the usual even bedded dolomites. No fossils were found in these included rocks, but elsewhere such bodies of limestone have given evidence of reef structure. It is therefore believed that the Virginia occurrences belong to the same class. A good example of such a reef may be seen along the Norfolk and Western railroad, one-half mile northwest of the station at Narrows, Va. Views of this occurrence are given on plate XIX, figure 1, showing the even bedded Lower Knox limestone overlapping upon the reef, while in figure 2 is a nearer view of the reef structure.

Shenandoah limestone.—This name has been applied by the U. S. Geological Survey to limestone overlying the interval between Lower Cambrian and Ordovician deposits in the eastern part of the Great Valley in southwestern Virginia. Apparently the Nolichucky shale is absent in this area and the separation of the Knox dolomite and Honaker limestone as distinct formations becomes difficult if possible at all. More study is required before anything definite can be said concerning these more eastern outcrops, and for the present the term Shenandoah limestone may be provisionally employed. The Shady limestone and Wautaga shale divisions of the Shenandoah, discussed in the stratigraphy of northwestern and central western Virginia, may be recognized in this part of the state also, but descriptions and analyses of these strata are given on later pages.

Ordovician Formations.

The most promising sources of supply for cement materials in southwestern Virginia, as elsewhere in the Appalachian Valley, are of Middle

Ordovician age. These strata therefore have been studied in more detail by the writer, and more numerous analyses have been made.

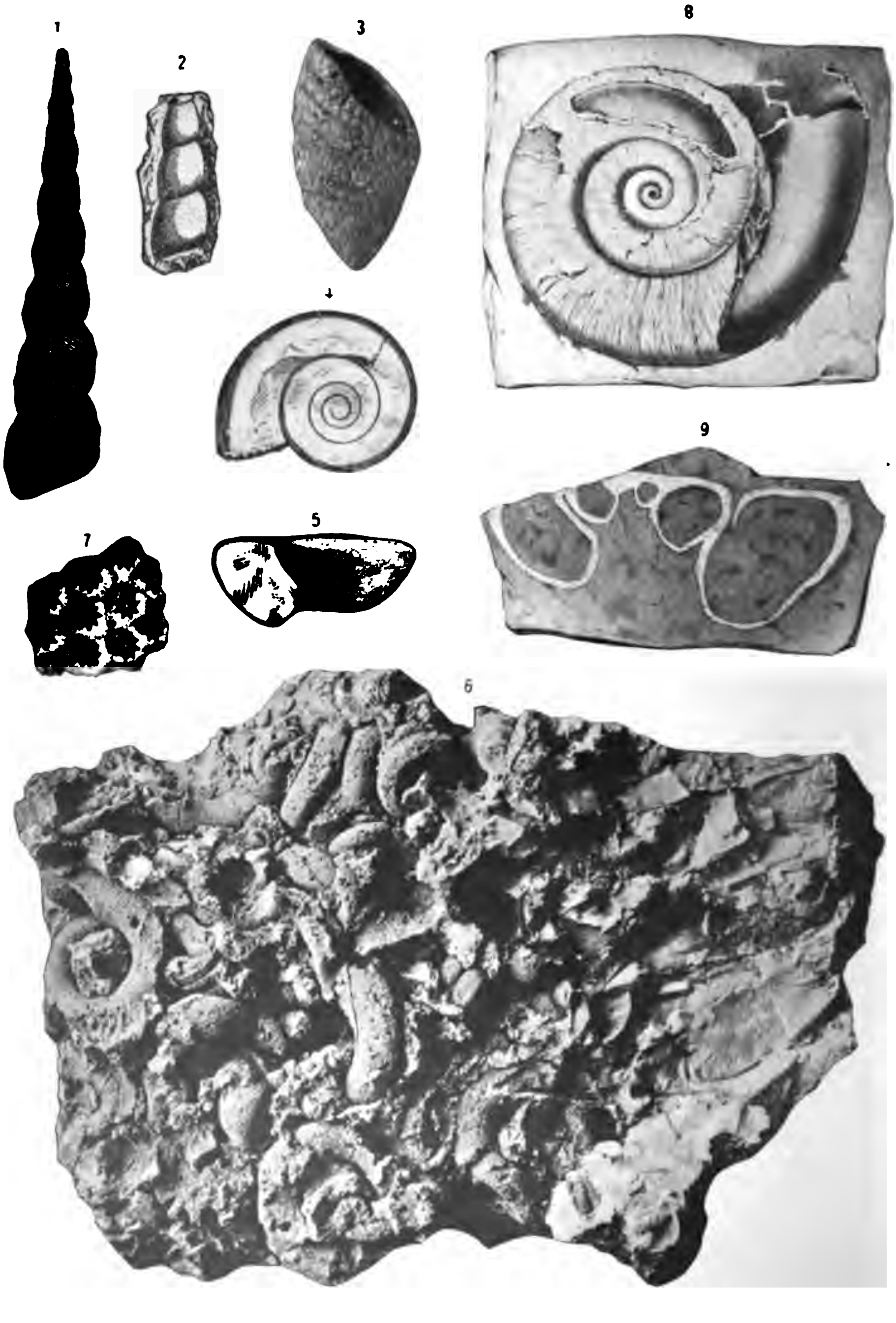
On account of the variation in the Ordovician formations in this particular part of the Appalachians, various names have been applied to the several lithologic units. These names, as well as the sequence of formations in the different areas of outcrop, have been indicated in the table on page 146. In this table, however, a name hitherto most commonly applied to the Ordovician limestones of the southern Appalachians, has been cited in only two of these areas, and explanations regarding this formation—the Chickamauga limestone—are in order.

Chickamauga limestone.—The Ordovician limestone exposed in the westernmost outcrops of the Appalachians show a considerable thickness when compared with limestones farther east belonging to the same period of time. To this thick limestone formation, the name Chickamauga limestone was applied by Dr. Hayes,[a] and has been employed on the maps of many of the Valley folios. The separation and delimitation of this purer limestone from the great underlying dolomitic series was a distinct advance in mapping, and the name was subsequently employed for any or all of the purer Ordovician limestones following the Knox dolomite. As mapping proceeded, other Ordovician formations were distinguished, especially by members of the U. S. Geological Survey. Thus the red impure limestones succeeding the purer blue limestone in Virginia and Tennessee was separated as the Moccasin formation; in addition, several distinct Ordovician shale formations were recognized and named. In all of these instances, however, the Chickamauga limestone was recognized as the more or less pure limestone strata immediately following the Knox dolomite. Its lower boundary was thus fixed, but the upper limit was naturally variable.

At the typical Chickamauga outcrops along Chickamauga creek east of Chattanooga, Tenn., this limestone appears to contain representatives of all the geological formations of the general time scale between the top of the Knox dolomite and the base of the Silurian. The name is therefore equivalent to the Middle and Upper Ordovician as commonly understood, and its application to strata with a less time range is not strictly correct.

With this explanation in mind, it will be noted that in the type areas the Chickamauga represents not only the Ordovician limestone but also the succeeding shales and sandstones of Virginia localities. In the eastern part of the Appalachian Valley the name has been applied to the strata now

[a] Geol. Soc. Amer., Bull. 1890, Vol. 2, p. 143.



UPPER KNOX (BEEKMANTOWN) AND STONES RIVER FOSSILS.

Figs. 1, 2.—*Hormotoma artemesia* (Billings). An entire specimen, natural size, and cast of fragment of this rather common species.

Fig. 3.—Operculum of an undetermined gastropod, probably a species of *Maclurea*, from chert near top of Beekmantown at Wytheville, Va.

Figs. 4, 5.—*Maclurea oceana* (Billings). Top and side views of a specimen, natural size.

Fig. 6.—A fragment of chert showing casts of coiled gastropods. Middle Knox, near Tazewell, Va.

Fossils of Stones River limestone.

Fig. 7.—Surface, × 5, of the coral *Stylarea parva* (Billings). The indented cells and the central column make the species easy of recognition.

Figs. 8, 9.—*Maclurea magna* (Lesueur). Top view and a cross section of this characteristic gastropod. About one-half natural size.

With the exception of 3, these figures are copied from various authors.

EXPLANATION OF PLATE XX.

referred to the Stones River formation; farther west the Holston marbles and limestones have been mapped as the Chickamauga, while in Powell river valley, strata of Stones River, Black River, and Trenton age have been grouped under the same name.

In spite of this technically incorrect use of the term, the name has been useful in distinguishing the Ordovician purer limestone, especially in areas where it seemed inadvisable to attempt a further division.

The Federal Survey has recommended that the writer continue the use of the Chickamauga limestone in the Copper creek and Powell valley areas of Virginia until an opportunity is afforded to present the complete evidence upon which he bases the correlations indicated in the present report.

AREAS OF DISTRIBUTION.

On account of the diverse character of the rocks, the simplest method in outlining the Ordovician stratigraphy of southwestern Virginia seems to be a consideration of the strata by areas of distribution. These areas are in a general way bounded by the major faults of the region. Their geographical boundaries therefore need not be described in detail, as a glance at the map on page 142 will readily determine them. Five areas are recognized and to these, for convenience of description, local names are here applied. These are, in order from east to west, (1) the Bristol area limited on the west by the Walker mountain fault; (2) the Walker mountain area included between the fault of the same name and the Saltville fault; (3) the Clinch mountain area bounded by the Saltville and Copper creek faults; (4) the Copper creek area, a narrow strip between the last mentioned fault and the Hunter valley fault, and (5) the Powell valley area comprising the remaining portion of the state in which Ordovician outcrops may be found.

Bristol Area.

The sequence of strata found above the Knox dolomite in the Bristol area was observed as far north as Montgomery county, but the principal outcrops are located in Washington county, east of Bristol. The section repeated from a former page for convenience of reference is as follows:

		Feet.
4.	Thin-bedded sandstones and sandy shales (Tellico)	1,000
3.	Blue to black calcareous and sandy shales (Athens)	1,000
2.	Thin siliceous blue and purer dove limestone, often wanting (Stones River)	0–30
1.	Knox dolomite (Beekmantown)	——

Of these formations the only one of importance as a possible source of cement material is the Athens shale. The composition of the Tellico naturally precludes its use, while the Stones River limestone, although sometimes of favorable composition for mixture with the overlying shales, is usually so little developed that it need not be considered in any detail. Both the Stones River limestone and the Athens shale are well represented in the next western area, so descriptions of their lithologic characters and analyses of the rock are reserved for that portion.

Both in Virginia and Tennessee the Tellico sandstone is limited to the eastern part of the Appalachian Valley, and in both states it consists of sandy shales and thin-bedded reddish sandstones overlying the Athens shale. In Virginia the Tellico caps the highest ridges along the southeastern margin of the Valley.

Walker Mountain Area.

A variety of cement rocks are offered in this area, but unfortunately the strip is so narrow and the railroad facilities so poor that the economic value of these materials is greatly lessened. The section seen along the railroad from Glade Spring to Saltville, already mentioned, furnishes good exposures of all the formations.

Another section across this band of outcrop is that exposed along the northwestern side of Walker mountain, north of Marion, Va. This section is as follows:

Walker mountain section, north of Marion, Va.

	Feet.
Clinch sandstone:	
Massive white quartzite and sandstone forming crest and southern slope of mountain	100±
Bays sandstone:	
Red to brown sandstone, sandy shale and conglomerate	300
Sevier shale:	
Brown to olive and gray shales, calcareous in basal part, argillaceous above and arenaceous in upper third	1,500
Moccasin limestone:	
Impure and argillaceous limestone	300
Holston marble and associated strata:	
(e) Unfossiliferous drab shales	40
(d) Nodular limestone and yellowish to gray shales holding many bryozoa	30
(c) Massive gray and pink marble with numerous bryozoa, *Solenopora* and *Stylarea parva*	30
(b) Clayey nodular limestone and shale. Some of the layers are crowded with *Receptaculites*	50
(a) Massive crystalline limestone	40
Athens shale:	
Dark to black shale with black slaty limestone at the base. Linguloids and trilobites are abundant in the basal beds	500±

Stones River formation:	
(c) Coarsely crystalline gray to blue limestone weathering into layers one to four inches in thickness. Upper beds pinkish and of a marble-like structure	100
(b) Mottled gray massive magnesian limestone. *Stylarea parva* the most characteristic fossil	40
(a) Massive dove limestone speckled with calcite spots. Gastropods, especially a large *Maclurea*, the most abundant fossils	30
Knox dolomite:	
Massive grayish dolomite with little chert	——

Stones River limestone.—In a previous publication the writer has correlated the lowest Ordovician limestone, following the Knox dolomite in this area, with the Lenoir limestone of eastern Tennessee. More study has shown that the formation name Stones River is more fitting for these strata, which consist of two members, an upper of mottled and other strata, and a lower of dove limestone. The occurrence and description of these two members are given in the discussion of central western Virginia (pages 106 and 107), and, as these strata in the southwestern part of the state are undoubtedly their southern extension, repetition is unnecessary.

The upper member of this limestone is of particular interest paleontologically on account of its typical Chazy fauna, a few of the characteristic species being illustrated on the accompanying plate. The analyses presented below are of samples selected from the better grade of Stones River rocks.

Analyses of Stones River limestone.

(J. H. Gibboney, Analyst.)

	I.	II.	III.
	Per cent.	Per cent.	Per cent.
Insoluble	4.60	7.34	16.12
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	0.24	0.88	3.20
Lime (CaO)	51.90	48.04	42.74
Calcium carbonate ($CaCO_3$)	92.68	85.78	76.32
Magnesia (MgO)	1.06	3.07	1.34
Magnesium carbonate ($MgCO_3$)	2.32	6.45	2.82
Total	99.84	100.45	98.46

I and II. Slightly magnesian limestones, 4 miles south of Saltville, Va.
III. Argillaceous limestone, Lyon Gap section (Bed 3), Smyth county.

Athens shale.—Resting either upon the Stones River limestone, or, when this is absent, upon the Knox dolomite, are dark and blue calcareous shales named from Athens, McMinn county, Tennessee, where they are well developed. In Virginia, these shales attain a maximum thickness of 1,000

or 1,200 feet. The lower strata are black carbonaceous shales passing into blue calcareous shales, which, as the top of the formation is approached, become more and more sandy. A few dark, fine-grained limestone bands occur in the lower part of these shales, but they are developed too sparingly to be of use. In folio No. 59 of the U. S. Geological Survey, the more important Athens shale areas of Virginia are shown. The composition of all the samples selected for analysis is given below. These analyses, which are of only the lower and middle divisions, indicate the value of this shale as a cement material. It will be noted that while the percentage of calcium carbonate is very favorable in these samples, the ratio between silica and iron-alumina is too high for a good cement material.

Analyses of Athens shale.

(J. H. Gibboney, Analyst.)

	I.	II.	III.	IV.
	Per cent.	Per cent.	Per cent.	Per cent.
Insoluble	19.48	11.24	5.82	17.64
Organic matter	1.28	0.60	——	0.08
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	1.28	0.96	0.54	1.40
Lime (CaO)	42.20	48.62	47.32	43.84
Calcium carbonate ($CaCO_3$)	75.36	86.82	84.50	78.28
Magnesia (MgO)	1.16	Tr.	4.16	1.26
Magnesium carbonate ($MgCO_3$)	2.45	Tr.	8.74	2.64
Total	99.85	99.62	99.60	100.04

	V.	VI.	VII.
	Per cent.	Per cent.	Per cent.
Insoluble	11.40	25.80	17.58
Organic matter	0.82	——	——
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	1.38	3.74	2.44
Lime (CaO)	47.14	37.96	43.44
Calcium carbonate ($CaCO_3$)	84.18	67.36	77.59
Magnesia (MgO)	0.95	0.12	0.04
Magnesium carbonate ($MgCO_3$)	2.00	0.24	0.08
Total	99.78	97.14	97.69

I. Calcareous shale, 2 miles south of Abingdon, Va.
II. Shaly limestone, 3 miles east of Bristol, Va.
III. Limestone band, 4 miles east of Bristol, Va.
IV and V. Dark shales, about 5 miles south of Saltville, Va.
VI. Dark shales (bed 4), Lyon Gap section, Smyth county.
VII. Dark blue shales (bed 4), Lyon Gap section, Smyth county.

Holston marble and associated strata.—The Ordovician limestone mapped by the U. S. Geological Survey in the vicinity of Knoxville, Tennessee, as the Chickamauga, contains beds of marble in its upper part, distinguished as the Holston marble. This marble and thin shale beds accompanying it hold a fauna of bryozoa, crinoids, cystids, and sponges so different from other Ordovician formations that this Holston division or its equivalent can easily be recognized elsewhere. In some parts of Virginia and Tennessee these shales and marble immediately follow the Knox dolomite; elsewhere they rest upon the Stones River limestone or its equivalent, as at Knoxville, Tenn.; again, in more eastern belts, where the marble is comparatively thin, either the Athens shale or both the Athens and Stones River may intervene. The best development of the Holston marble is in the Clinch mountain area, so that further remarks and analyses of the strata are reserved for that section.

The Ordovician formations overlying the Holston are likewise better developed in the next area, and a description of these also is reserved. The Walker mountain area is of particular interest in showing the overlap of Holston strata upon the Athens formation, thus fixing the place of the latter in the geological column.

The term Holston was proposed for the marble lentil in the Chickamauga limestone of the Walker mountain and Clinch mountain areas, but recently[a] the writer has extended its limits so as to include the associated limestone and shales holding a fauna identical with that of the marble itself. This course has been objected to by the U. S. Geological Survey, which holds that the name should be retained with its original meaning. Therefore in the present work the writer treats this formation under the designation of the Holston marble and associated strata.

Clinch Mountain Area.

In southwestern Virginia and Tennessee this area comprises the most important marble regions, so that this industry will probably always remain the most important. Associated with these marbles is a variety of limestones and shales of interest from the standpoint of cement materials. These Holston marbles and associated limestones and shales rest directly upon the Knox dolomite. Following this formation are the Moccasin limestone, Sevier shale, and Bays and Clinch sandstones, similar in character but better developed than in the Walker mountain area. It will thus be noted

[a] Mineral Resources of Virginia, 1907, p. 135.

that these two areas of deposition differ only in the absence of the Stones River limestone and Athens shale from the more western one. Sections of the Knox dolomite and underlying formations of the Clinch mountain area have been given on previous pages.

Holston marble and associated strata.—The origin of this name and the reasons for recognizing these strata as a distinct formation have been given on page 163. A fair idea of the strata in Virginia comprised in the Holston may be had from the geologic section exposed at Speer Ferry in Scott county. The lower strata are exposed along the Virginia and Southwestern railroad and the higher beds may be seen on the northeast slope of Clinch mountain. The various divisions in this section are arranged with reference to the character of the rock. Fossils are most abundant in the middle and upper portions, although careful search shows many species in the marbles and associated beds.

Section of Holston marble and associated strata, vicinity of Speer Ferry, Va.

	Thickness in feet.
Moccasin limestone:	
Red argillaceous limestones and calcareous shales	——
Holston marble and associated strata:	
(l) Yellow to bluish gray shales and laminated earthy and shaly limestone	250
(k) Blue to gray coarsely crystalline limestone weathering into thin, somewhat nodular layers	80
(j) Shales and thin irregular platy limestone interbedded. Fossils most numerous in this division, *Receptaculites biconstrictus* and *Echinosphærites* being characteristic forms	200
(i) Light gray and pinkish marble, heavy and thin-bedded	150
(h) Cherty limestone with shales in lower part	20
(g) Gray marble	25
(f) Shaly blue limestone	30
(e) Gray marble holding *Solenopora* and ostracoda	10
(d) Blue laminar limestone	17
(c) Gray marble in several layers with shaly partings	15
(b) White and pink, rather fine-grained marble	32
(a) Thin- and heavy-bedded earthy siliceous limestone with nodules of black chert	50
Knox dolomite (Beekmantown):	
Massive white, argillaceous limestone with an uneven, siliceous, probably conglomeratic bed at the top	——

Sections differing but little from the above are exposed at Gate City and other points in Scott and Russell counties just northwest of Clinch mountain. In all of these a three-fold division of the formation may be

noted, (1) a lower division of cherty thin- to heavy-bedded siliceous limestone at the base, (2) marble with shales and limestones in which the marble predominates, and (3) a division of more shaly strata at the top.

In the Walker mountain area, 200 feet of marble and limestone with interbedded calcareous shales overlying the Athens shale have been identified as the Holston on account of the similarity of their fossil contents and lithology as well.

Although this formation contains a variety of diverse strata, still all of them are low enough in magnesia to be considered as cement materials. The considerable range in composition of these strata is shown in the following analyses. This, in connection with the diverse kinds of rocks in the formation, is rather against their use in cement manufacture. The lowest strata are siliceous and besides contain too many chert nodules to be considered. The succeeding marbles are excellent when used as a mixing material.

Analyses of Holston marble and associated limestones and shales.

(J. H. Gibboney, Analyst.)

	I.	II.	III.	IV.	V.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Insoluble	23.54	0.86	39.52	33.80	10.56
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3) }	3.52	1.10	5.64	4.36	2.24
Lime (CaO)	39.86	55.00	28.44	35.14	48.06
Calcium carbonate ($CaCO_3$)	71.18	98.21	50.70	59.18	85.82
Magnesia (MgO)	0.88	0.08	0.88	0.66	0.70
Magnesium carbonate ($MgCO_3$)	1.78	0.17	1.85	1.38	1.43
Total	100.02	100.34	97.71	98.72	100.05

	VI.	VII.	VIII.	IX.
	Per cent.	Per cent.	Per cent.	Per cent.
Insoluble	10.10	9.48	8.16	4.66
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3) }	2.36	2.34	1.24	1.46
Lime (CaO)	49.70	49.12	49.76	51.50
Calcium carbonate ($CaCO_3$)	85.72	87.71	88.86	91.96
Magnesia (MgO)	0.21	0.35	0.75	0.51
Magnesium carbonate ($MgCO_3$)	0.44	0.75	1.58	1.06
Total	98.62	100.27	99.84	99.14

	X.	XI.	XII.	XIII.
	Per cent.	Per cent.	Per cent.	Per cent.
Insoluble	12.18	14.96	8.26	8.42
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3) }	0.98	1.70	1.82	3.66
Lime (CaO)	47.56	45.08	50.40	47.12
Calcium carbonate ($CaCO_3$)	84.93	80.50	90.89	84.14
Magnesia (MgO)	0.75	0.38	0.12	0.67
Magnesium carbonate ($MgCO_3$)	1.58	0.81	0.26	1.41
Total	99.67	97.97	101.23	97.63

I. Calcareous shale interbedded with Holston marble, 5 miles south of Saltville, Va.
II. Light-colored, coarsely crystalline marble, base of formation, Speer Ferry, Va.
III. Blue shale, succeeding marble, in lower part of formation, Speer Ferry, Va.
IV. Drab shale, middle portion of formation, Speer Ferry, Va.
V. Bluish argillaceous limestone, upper part of formation, Speer Ferry, Va.
VI. Dark argillaceous limestone, upper part of formation, Speer Ferry, Va.
VII. Heavily bedded argillaceous limestone, 3 miles north Mendota, Va.
VIII. Dove limestone, 3 miles north Mendota, Va.
IX. Thin-bedded argillaceous and crystalline limestone (bed 5), Lyon Gap section, Smyth county, Va.
X. Blue argillaceous limestone (bed 6), Lyon Gap section, Smyth county, Va.
XI. Gray argillaceous limestone (bed 6), Lyon Gap section, Smyth county, Va.
XII. Dark argillaceous limestone, Gate City, Va.
XIII. Blue argillaceous limestone, Gate City, Va.

Most of the species of the Holston fauna are undescribed, but probably the most characteristic is the very abundant *Receptaculites* figured on plate XXI. A solid ramose bryozoan, likewise figured on this plate, is *Batostoma sevieri,* distinguished by its unusually large cells. Other characteristic fossils are the cup-shaped bryozoan described by Ulrich as *Scenellopora radiata,* and the crinoid *Diabolocrinus vesperalis*. The peculiar organism, *Solenopora compacta,* although not characteristic of this formation alone, is sometimes so abundant that entire layers are crowded with its rounded, whitish, finely porous masses.

Moccasin limestone.—In the Walker mountain, Clinch mountain, and Copper creek areas of southwestern Virginia, the several Middle Ordovician limestones are followed by an argillaceous red limestone named as above from its occurrence along Moccasin creek in Scott county. Along Clinch mountain, in both Virginia and Tennessee, the best development of this impure limestone occurs, with a thickness varying from 300 to 500 feet.

EXPLANATION OF PLATE XXI.

Figs. 1–3.—*Batostoma sevieri*, n. sp. Three examples, natural size, of this ramose bryozoan. The species is very abundant in the Holston beds and may be readily recognized by its method of growth, and the large, thin-walled polygonal zooecia.

Figs. 4, 5.—*Receptaculites biconstrictus*, n. sp. (Ulrich MS.).

4. Upper surface of an unweathered average example showing the rhomboidal plate-like expansion of the outer ends of the columns making up the walls of this peculiar organism. In all other known species of this genus the columns have a single constriction, just within the outer plate-like expansion. In the present form, a second constriction occurs about mid-length of the column. This figure suggested the specific name given in manuscript by Mr. E. O. Ulrich some years ago.

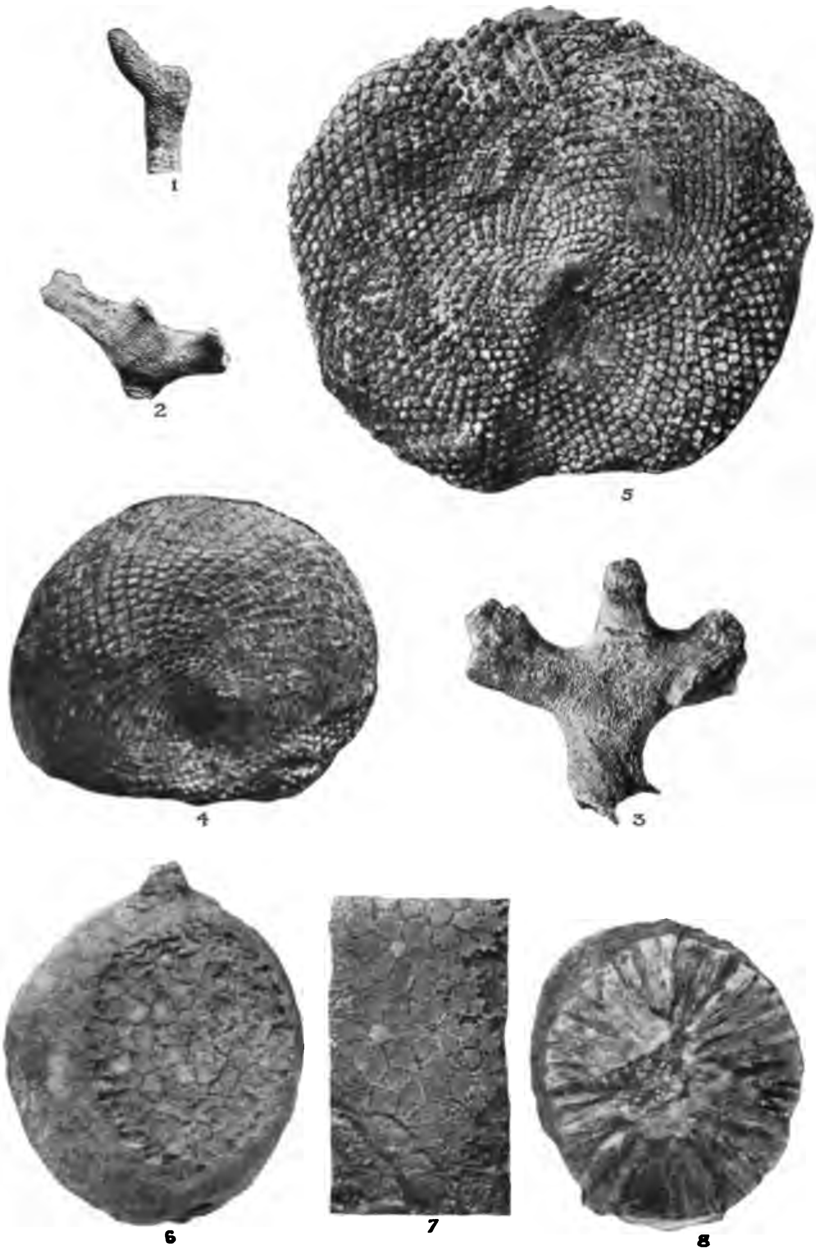
5. The upper surface of a larger example weathered so as to show the isolated cylindrical columns beneath the surface expansion.

Figs. 6–8.—*Echinosphaerites aurantium* (Hisinger).

6. An uncrushed average example of this ball-like cystid.

7. Surface of a slightly abraded specimen, × 2, showing the parallel canals which traverse the interior of the plates.

8. A fractured specimen filled with calcite. The radially disposed prismatic crystals of the latter are peculiar in that their faces correspond to the plate outlines of the cystid.



CHARACTERISTIC FOSSILS OF HOLSTON MARBLE AND ASSOCIATED SHALES.

The Moccasin limestone has been regarded as an intermediate or transition formation between the great Ordovician limestone development in Powell valley and the equally great development of shale and sandy strata of the easternmost portions of the Appalachian Valley. If continuous exposures could be had, this formation would then under this view be seen to blend well with the limestones of the west and change to shale in the eastern areas. More recent investigations have shown that the Moccasin represents but a single formation of the Ordovician sediments, and although fossil evidence is somewhat scarce, it has been found to be of Middle Ordovician age.

Although the strata are in general of red argillaceous material, blue, drab, dirty dove and greenish-tinted layers are occasionally seen. These variously colored layers are invariably composed of impure calcareous muds. Granular limestones are so infrequent that they can be neglected in a discussion of these rocks. Upon fresh exposures, the Moccasin strata are apparently quite massive, but weathering soon reduces them to shaly material and later to a reddish, rather fertile soil. Outcrops of the Moccasin are usually along the slopes of the mountains or ridges. The following table gives analyses of samples from various points in southwestern Virginia, which indicate a rather uniform composition for the rock. It will further be noted that, although a rather favorable percentage of calcium carbonate for cement purposes is present in these rocks, the comparatively large amount of insoluble material is equally unfavorable.

Analyses of Moccasin limestone.

(J. H. Gibboney, Analyst.)

	I.	II.	III.	IV.	V.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Insoluble	23.58	8.28	24.72	13.20	11.73
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	1.18	1.72	3.94	2.66	1.48
Lime (CaO)	40.34	49.36	38.48	45.40	47.78
Calcium carbonate ($CaCO_3$)	72.04	88.23	68.71	81.07	85.32
Magnesia (MgO)	0.83	0.96	0.64	0.87	0.24
Magnesium carbonate ($MgCO_3$)	1.74	2.02	1.35	1.83	0.58
Total	98.64	100.25	98.72	98.76	99.11

	VI.	VII.	VIII.	IX.	X.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Insoluble	7.66	6.90	34.28	32.24	23.86
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3) }	0.82	1.24	4.96	4.50	4.40
Lime (CaO)	50.38	50.10	31.88	33.96	35.96
Calcium carbonate ($CaCO_3$)	89.96	89.48	56.92	60.64	64.26
Magnesia (MgO)	0.35	0.75	0.68	0.25	0.55
Magnesium carbonate ($MgCO_3$)	0.76	1.57	1.44	0.53	1.17
Total	99.20	99.19	97.60	97.91	98.60

I. Argillaceous limestone about 5 miles south of Saltville, Va.
II. Impure drab limestone, Tazewell county, Va.
III. Impure red limestone, Five Oaks, Va.
IV. Dove-colored, argillaceous limestone, Five Oaks, Va.
V. Granular blue limestone, Five Oaks, Va.
VI. Red clayey limestone, Pearisburg, Va.
VII. Red limestone, near Goodwin Ferry, Va.
VIII. Red shales, vicinity of Speer Ferry, Va.
IX. Red shaly limestone, Gate City, Va.
X. Red shaly limestone, 3 miles north of Mendota, Va.

Sevier shale.—The great Ordovician shale formation of southwestern Virginia has been mapped by the U. S. Geological Survey under the name of Sevier shale. In Sevier county, Tennessee, the Tellico sandstone is followed by a shale formation of Middle and Upper Ordovician age. Although fossils are rare in these shales, sufficient evidence has been found to indicate that the strata are probably of Trenton, Utica, and Eden age. In southwestern Virginia, the shale formation referred to the Sevier is more abundantly fossiliferous, and its stratigraphic relations to the Trenton, Utica, and Eden of the general time scale can be determined with more precision. On a previous page, similar age relations for the Martinsburg shale have been noted, so that these various shale formations are essentially the same stratigraphically.

The lithological features of the Sevier are also quite similar to the Martinsburg, so that a detailed description is unnecessary. The lower strata are of calcareous shale and interbedded limestone, the middle portion is more argillaceous, while the upper beds are quite sandy. The lower and middle portions, therefore, are of value as a source of cement rock. All the various horizons of the Sevier are represented in the table of analyses below, but most of the samples were obtained from the more important lower portion.

Analyses of Sevier limestones and shales.

(J. H. Gibboney, Analyst.)

	I.	II.	III.	IV.	V.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Insoluble	4.74	29.90	11.68	20.48	22.50
Alumina (Al_2O_3) }	1.72	2.02	1.52	2.04	2.34
Iron oxide (Fe_2O_3) }		1.30			
Lime (CaO)	51.92	36.80	48.08	42.76	41.34
Calcium carbonate ($CaCO_3$)	92.71	65.72	85.86	76.36	73.82
Magnesia (MgO)	0.13	0.58	0.45	0.51	0.05
Magnesium carbonate ($MgCO_3$)	0.27	1.23	0.94	1.06	0.11
Total	99.44	100.17	100.00	99.94	98.77

	VI.	VII.	VIII.	IX.	X.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Insoluble	8.14	28.62	73.00	29.70	5.12
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3) }	1.24	3.76	11.28	3.18	2.92
Lime (CaO)	50.54	36.42	6.76	36.16	51.16
Calcium carbonate ($CaCO_3$)	90.25	65.03	12.07	64.57	91.39
Magnesia (MgO)	0.28	0.99	0.04	0.60	0.25
Magnesium carbonate ($MgCO_3$)	0.58	2.08	0.09	1.26	0.53
Total	100.21	99.49	96.44	98.71	99.96

	XI.	XII.	XIII.	XIV.
	Per cent.	Per cent.	Per cent.	Per cent.
Insoluble	41.48	71.88	7.08	33.40
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3) }	6.04	8.56	1.88	4.92
Lime (CaO)	28.00	8.54	50.60	32.86
Calcium carbonate ($CaCO_3$)	50.00	15.25	90.36	58.68
Magnesia (MgO)	0.30	1.27	0.41	0.18
Magnesium carbonate ($MgCO_3$)	0.64	2.68	0.87	0.38
Total	98.16	98.37	100.19	97.88

	XV.	XVI.	XVII.	XVIII.
	Per cent.	Per cent.	Per cent.	Per cent.
Insoluble	55.60	23.48	55.55	39.20
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3) }	7.60	3.86	8.37	5.80
Lime (CaO)	18.20	39.44	18.41	29.20
Calcium carbonate ($CaCO_3$)	32.50	70.53	32.68	52.16
Magnesia (MgO)	0.61	0.09	0.72	0.07
Magnesium carbonate ($MgCO_3$)	1.29	0.18	1.51	0.15
Total	96.99	98.05	98.31	97.31

I. Limestone band, lower part of formation, about 6 miles south of Saltville, Va.
II. Calcareous shales, lower part of formation, about 6 miles south of Saltville, Va.
III. Compact, black limestone, Trenton horizon, Tazewell, Va.
IV. Calcareous shales, Trenton horizon, Tazewell, Va.
V. Compact argillaceous layers, lower part of formation, Five Oaks, Va.
VI. Limestone bands, lower part of formation, Five Oaks, Va.
VII. Calcareous shales at base of formation, Five Oaks, Va.
VIII. Sandy shales, upper part of formation, Five Oaks, Va.
IX. Calcareous shales, northern part of Wythe county, Va.
X. Thin-bedded blue limestone, lower part of formation (Trenton), near Goodwin Ferry, Va.
XI. Calcareous shales, near Goodwin Ferry, Va.
XII. Sandy shales from Eden horizon, near Goodwin Ferry, Va.
XIII. Thin-bedded black limestone, Trenton horizon, Speer Ferry, Va.
XIV. Calcareous shales, Trenton horizon, Speer Ferry, Va.
XV. Sandy shales, Eden horizon, Speer Ferry, Va.
XVI. Calcareous shales, basal portion of formation, Gate City, Va.
XVII. Upper part of formation, Gate City, Va.
XVIII. Calcareous shale, 3 miles north of Mendota, Va.

Bays sandstone.—In the Bays mountains of Tennessee, the Sevier shales are overlain by red sandy shales grading upward into red sandstones which have been mapped as a separate formation. This, the Bays sandstone, contains fossils of Lorraine age and is one of the more widespread formations in both Tennessee and Virginia. Its outcrops are generally near the summits of the Valley ridges, but the strata are usually concealed by débris from the formation above. A single sample was taken for analysis.

Analysis of Bays sandstone, near Glade Spring, Va.

(J. H. Gibboney, Analyst.)

	Per cent.
Insoluble	90.18
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	5.72
Lime (CaO)	0.64
Calcium carbonate ($CaCO_3$)	1.14
Magnesia (MgO)	0.03
Magnesium carbonate ($MgCO_3$)	0.07
Total	97.11

Clinch sandstone.—All the more prominent Valley ridges owe their existence to this heavy sandstone. The Clinch is a massive, coarse, white sandstone or quartzite 200 to 300 feet thick, and is prominently displayed along Clinch mountain, the most conspicuous of the Valley ridges. The sandy nature of both the Clinch and the underlying Bays prevent their use as cement materials. The characteristic fossils of the Clinch and Bays have been figured on plates VIII and XIV.

Copper Creek Area.

Recent studies have shown that the area included by the Copper creek and Hunter valley faults presents two successions of Ordovician strata. In Scott and Russell counties the strata between the Knox and Moccasin can be referred definitely to the Holston marble and associated strata of the same age. In the three more northern counties, Tazewell, Bland, and Giles, exact correlation of the rocks in the same interval is difficult, and until more detailed study and further field work can be put upon the faunas, it was first thought advisable to employ provisionally a manuscript name, the Pearisburg limestone, applied to these rocks by Mr. M. R. Campbell some years ago. The consistent use by members of the Federal Geological Survey of the term Chickamauga limestone for these same rocks has given this name standing in the area. The U. S. Geological Survey has advised continuing this use of Chickamauga limestone until some definite knowledge of the rocks is at hand, when the more limited term Pearisburg limestone may prove of value.

The strata making up this formation are of rather diverse materials, although mainly of limestone. The upper layers are usually shaly dove limestone similar lithologically and also faunally to strata in Powell valley correlated with the Tyrone formation. The lower beds are of more massive, crystalline fine- to coarse-grained limestone holding faunas recalling the Chazy formation. The several sections given below will illustrate the usual character of the Chickamauga limestone in this area. No attempt is made at present to give the characteristic fossils of the several divisions. At Pearisburg, Giles county, the following section is exposed:

Geologic section, Pearisburg, Va.

	Feet.
4. Sevier shale	——
3. Moccasin limestone. Purple calcareous shales and argillaceous limestones with seams of impure dove limestone	200
2. Chickamauga limestone:	
(f) Light gray compact limestone with gastropoda abundant in the lower beds and numerous ostracoda in the upper part	60
(e) Fine-grained dove limestone	20
(d) Imbedded magnesian limestone	25
(c) Light to dark gray moderately fine-grained limestone in lower part and massive cherty beds in upper division	65
(b) Dark bluish-gray limestone, subcrystalline or earthy in the upper part and slightly cherty in the lower beds. A *Girvanella* less than 0.5 inch in diameter very abundant	50
(a) Dark gray mottled massive limestone leaving a deep red chert upon weathering. Fossils numerous, bryozoa, brachiopods, and *Solenopora* being particularly abundant	250
1. Knox dolomite. Magnesian limestone weathering into reddish chert	——

Other sections in the vicinity of Pearisburg are given under the discussion of Giles county. In order to show the general composition of these various limestones, all of the analyses have been tabulated as below.

Analyses of Chickamauga limestone, vicinity of Pearisburg, Va.

(J. H. Gibboney, Analyst.)

	I.	II.	III.	IV.	V.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Insoluble	6.14	7.86	5.02	3.88	3.14
Organic matter	0.26	——	0.43	——	——
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	0.94	0.90	1.00	0.50	1.58
Lime (CaO)	50.30	48.00	51.36	52.00	51.60
Calcium carbonate ($CaCO_3$)	89.82	85.72	91.71	92.84	92.14
Magnesia (MgO)	1.57	2.85	1.24	1.43	1.54
Magnesium carbonate ($MgCO_3$)	3.30	6.00	2.60	3.00	3.23
Total	100.44	100.48	100.76	100.22	100.09

	VI.	VII.	VIII.	IX.
	Per cent.	Per cent.	Per cent.	Per cent.
Insoluble	2.16	0.52	2.24	6.56
Organic matter	——	——	——	——
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	0.66	0.38	0.46	0.64
Lime (CaO)	50.30	51.24	53.80	50.28
Calcium carbonate ($CaCO_3$)	89.82	91.50	96.07	89.78
Magnesia (MgO)	3.62	3.66	0.48	1.66
Magnesium carbonate ($MgCO_3$)	7.60	7.68	1.00	3.48
Total	100.24	100.08	99.77	100.46

	X.	XI.	XII.	XIII.
	Per cent.	Per cent.	Per cent.	Per cent.
Insoluble	0.98	6.64	6.04	1.00
Organic matter	——	——	——	——
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	0.68	0.80	0.84	0.10
Lime (CaO)	54.88	50.80	51.20	54.83
Calcium carbonate ($CaCO_3$)	98.00	90.71	91.43	98.00
Magnesia (MgO)	0.20	1.04	0.80	0.18
Magnesium carbonate ($MgCO_3$)	0.43	2.18	1.67	0.38
Total	100.09	100.33	99.98	99.48

	XIV.	XV.	XVI.	XVII.
	Per cent.	Per cent.	Per cent.	Per cent.
Insoluble	1.42	3.26	1.17	2.12
Organic matter	——	——	0.25	0.18
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3) }	0.26	0.34	1.20	0.25
Lime (CaO)	54.84	52.90	——	——
Calcium carbonate ($CaCO_3$)	97.93	94.46	91.85	95.03
Magnesia (MgO)	0.11	0.98	——	——
Magnesium carbonate ($MgCO_3$)	0.23	2.05	5.52	2.40
Total	99.84	100.11	99.99	99.98

	XVIII.	XIX.	XX.	XXI.
	Per cent.	Per cent.	Per cent.	Per cent.
Insoluble	1.35	5.60	1.50	2.30
Organic matter	0.40	——	——	——
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3) }	0.43	0.78	0.58	0.60
Lime (CaO)	——	51.40	54.76	54.06
Calcium carbonate ($CaCO_3$)	96.04	91.60	97.78	96.54
Magnesia (MgO)	——	0.72	0.15	0.30
Magnesium carbonate ($MgCO_3$)	1.75	1.52	0.31	0.64
Total	99.97	99.70	100.17	100.08

I. Dark gray limestone (bed 2a), Pearisburg, Va.
II. Dark blue limestone weathering into chert (bed 2a), Pearisburg, Va.
III. Subcrystalline limestone (bed 2b), Pearisburg, Va.
IV. Light gray, massive limestone (bed 2c), Pearisburg, Va.
V. Dark, massive limestone (bed 2c), Pearisburg, Va.
VI and VII. Laminar, unfossiliferous limestone (bed 2d), Pearisburg, Va.
VIII. Fine-grained dove limestone (bed 2e), Pearisburg, Va.
IX. Semi-mottled limestone (bed 2f), Pearisburg, Va.
X. Coarsely crystalline gray limestone, near Goodwin Ferry, Va.
XI. Compact, dark argillaceous limestone, near Goodwin Ferry, Va.
XII. Dark, argillaceous limestone, near Goodwin Ferry, Va.
XIII. Dark, compact limestone, 1 mile south Eggleston, Va.
XIV. Crystalline limestone, near Goodwin Ferry, Va.
XV. Dove limestone, 1 mile south Eggleston, Va.
XVI, XVII, XVIII. Massive limestone from lower part of formation, Ripplemead, Va. Dr. Henry Froehling, analyst.
XIX. Compact, massive limestone, lower part of formation, vicinity of Narrows, Va.
XX. Thin-bedded blue limestone, middle portion of formation, vicinity of Narrows, Va.
XXI. Dove-colored compact limestone, upper part of formation, vicinity of Narrows, Va.

In Tazewell county, numerous outcrops of the Chickamauga limestone occur in close proximity to the railroad. These strata here are the massive

quarry rock and have been much used for lime-burning and other purposes. The Norfolk and Western railroad crosses or closely parallels the band of outcrop of which the following is a section.

Geologic section of Chickamauga limestone, vicinity of Tazewell, Va.

	Feet.
Chickamauga limestone:	
Laminar clayey limestone, unfossiliferous, blue gray to reddish in color	30
Massive subcrystalline gray crinoidal limestone	18.6
Fine-grained dove limestone	18
Yellow clayey limestone	18
Fine-grained dove limestone	24
Massive dove limestone	40
Thin-bedded dove limestone	45
Heavy- and thin-bedded dove limestone	75
Rather pure dove limestone	200
Dark gray siliceous limestone with dark flinty chert nodules	100
Massive dove limestone (the main quarry rock at Tazewell and Five Oaks)	40
Massive gray limestone giving rise to red soils with small chert nodules	40
Thin-bedded argillaceous greenish to yellow limestone	70
Knox dolomite	——

Sections similar to the above are shown in the vicinity of Five Oaks and at other points along the railroad.

In the Ordovician bands of outcrop southeast of Tazewell, somewhat similar sections are shown, differing mainly in a greater development of massive granular limestone in the basal part of the formation. Here also a basal conglomerate may sometimes be noted. The top surface of such a conglomerate is shown in figure 1, plate XXII. Various exposures along the north side of Thompson Valley give the following general section:

Geologic section along north side of Thompson Valley, Va.

	Feet.
Moccasin limestone:	
Red and drab impure argillaceous limestone	400±
Chickamauga limestone:	
Fine-grained shaly dove-colored limestone	75
Yellowish to red thin-bedded shaly limestone	80
Gray subcrystalline crinoidal limestone	36
Rather thin-bedded dove limestone, massive in lower part	75
Gray finely granular limestone holding *Maclurea magna*	125
Gray fine-grained massive limestone, somewhat cherty	90
Pinkish to purplish fine-grained and subgranular massive limestone, the lower layers yielding nodules of dark chert upon weathering	100
Knox dolomite:	——
Massive gray magnesian limestone.	
Chert with gastropods in upper part.	

Fig. 1.—Top surface of basal conglomerate in Chickamauga limestone along Thompson Valley road (14 miles southeast of Tazewell, Va.), one-half mile east of fork of Liberty and Flat Top Mountain Gap roads.

Fig. 2.—A hillside of dove (Chickamauga limestone, division 2) limestone showing occurrence of cedar trees, Pennington, Va.

BASAL CONGLOMERATE IN CHICKAMAUGA LIMESTONE AND HILLSI' OF DOVE LIMESTONE.

All of the analyses of Chickamauga limestone from Tazewell county are assembled in the following table. The high lime and low magnesian content, and small amount of clayey material shown in these strata are noteworthy. For lime-burning their value is apparent, but mixture with shale or clay would be necessary to make cement.

Analyses of Chickamauga limestone, vicinity of Tazewell, Va.

(J. H. Gibboney, Analyst.)

	I.	II.	III.	IV.
	Per cent.	Per cent.	Per cent.	Per cent.
Insoluble	2.04	1.80	5.36	2.82
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	0.50	1.00	0.72	0.78
Lime (CaO)	53.80	53.27	51.30	53.90
Calcium carbonate ($CaCO_3$)	96.07	95.42	91.64	96.25
Magnesia (MgO)	1.33	0.43	0.67	0.51
Magnesium carbonate ($MgCO_3$)	2.78	0.91	1.40	1.06
Total	101.39	99.13	99.12	100.91

	V.	VI.	VII.
	Per cent.	Per cent.	Per cent.
Insoluble	5.94	6.04	4.56
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	1.46	1.14	1.84
Lime (CaO)	51.34	51.20	49.14
Calcium carbonate ($CaCO_3$)	91.68	91.42	87.75
Magnesia (MgO)	0.33	0.43	2.09
Magnesium carbonate ($MgCO_3$)	0.70	0.91	4.40
Total	99.78	99.51	98.55

I. Massive finely crystalline limestone, near base of formation, Tazewell, Va.
II. Blue, coarsely crystalline limestone, near base of formation, Tazewell, Va.
III. Thin-bedded dove limestone, middle portion of formation, Tazewell, Va.
IV. Massive dove limestone, near top of formation, Tazewell, Va.
V. Granular blue limestone, Five Oaks, Va.
VI. Thin-bedded shaly limestone, Five Oaks, Va.
VII. Dove limestone, Five Oaks, Va.

Following the Chickamauga limestone in the Copper creek area are the Moccasin limestone, Sevier shale, Bays and Clinch sandstone described in the discussion of the Clinch mountain area.

Powell Valley Area.

Three well defined bands of Ordovician limestone outcrop in the Powell valley area, which according to the present arrangement includes all of southwestern Virginia west of the Hunter valley fault. These three bands are shown in order going west, (1) along the northwest slopes of Powell mountain, (2) on the same slope of Wallen ridge, and (3) along the western side of Powell valley. On account of folding and faulting, the westernmost region sometimes shows two strips of these strata increasing the area of outcrop. The general sequence of Ordovician rocks in this area has been noted in comparison on a preceding page. The following sections are introduced to show the more detailed character of the strata as well as their resemblance to each other in the several bands. The identification of the various formations is based primarily upon the fossils contained in the rocks, and as the details of these studies cannot be given in such a report, the results only have been noted. The most striking result of such studies in the rocks of this area is the recognition of their great paleontological and lithological similarity to the Middle and Upper Ordovician strata of central Tennessee, Kentucky, and Ohio. East of the Hunter valley fault the sequence is totally different, as may be noted by comparing the following sections with those on previous pages. This fault, therefore, apparently marks the dividing line or barrier between sediments of the Mississippi valley and those of the Appalachian provinces. It is also of interest that this fault likewise marks the eastern boundary of the great coal field of southwestern Virginia.

Following the usage of the U. S. Geological Survey, the mapable units, Clinch, Bays, Sevier, and Chickamauga formations are continued, but for purposes of detailed description, the formations recognized in the Ordovician section of Ohio, Kentucky, and central Tennessee are noted. Although complete lists of fossils and other evidence cannot be given here, it can be confidently stated that the Ordovician section in the Powell river valley is identical with that of the states just mentioned. The correlation of the formations in these areas is indicated in the following table:

Table of Ordovician formations.

Geologic units mapped by U. S. G. S. in Powell river valley of Virginia and Tennessee.	Geologic formation of Ohio, Kentucky, and central Tennessee.	Divisions of general time scale.
Clinch sandstone	Richmond	Richmond or Silurian
Bays sandstone	Lorraine	Lorraine
Sevier shale	Eden	Eden
Chickamauga limestone	Cathey Bigby Hermitage	Trenton
	Tyrone	Lowville (Birdseye)
	Stones River	Stones River
Knox dolomite (upper third)	———	Beekmantown

In the following sections the writer has numbered the divisions of the Chickamauga limestone, 1 being the equivalent of the Stones River formation, 2 of the Tyrone, and 3, 4, and 5 of the Hermitage, Bigby, and Cathey divisions of the Trenton, respectively.

The first section was obtained in Tennessee just south of the Virginia line and west of Sneedville, no opportunity being afforded to study the same general region in Virginia.

Geologic section from crest of Powell mountain northwest to Wallen ridge.

	Feet.
Clinch sandstone (crest of Powell mountain)	——
Bays sandstone and Sevier shale (Upper Ordovician):	
Mainly unexposed—basal shales only seen	——
Chickamauga limestone (Middle Ordovician):	
Division 5.	
Rather thin-bedded blue limestone holding many ramose bryozoa and other fossils. *Orthorhynchula linneyi* and *Hebertella sinuata* abundant	45
Subgranular and fine-grained bluish limestone full of gastropoda	35
Interbedded earthy, fine-grained and subgranular limestone with numerous *Zygospira recurvirostris* and *Plectambonites sericeus*	60
Division 4.	
Mostly bluish, subgranular limestone partly covered	80
Division 3.	
Nodular clayey limestone holding many hemispheric bryozoans	18
Blue granular limestone with *Dalmanella fertilis* and *Dinorthis pectinella*	25

Division 2.	
Thin-bedded shales and shaly limestone with an occasional layer of harder limestone	30
Thin shaly limestone and interbedded shales holding numerous bryozoa and ostracoda with the upper beds subgranular and crowded with crinoid fragments. At the top of this division is a plate 1 foot thick of chert-like limestone	40
Thin-bedded shaly limestone with few fossils	55
Thin- and thick-bedded drab limestone with black chert nodules in the upper part	100
Dove, drab to bluish fine-grained limestone with few fossils	100
Granular gray to blue limestone with light gray to dove clayey beds at the top	70
Division 1.	
Rather massive dove limestone	45±

The following is a generalized section of the Ordovician limestones and shales exposed along the western side of Powell valley. This section is compiled from the several sections given in more detail later in the discussion of Lee county.

Geologic section along western side of Powell Valley.

	Feet.
Silurian:	
Rockwood.	
Thin sandstones with a one-half inch band of iron ore near the base	——
Clinch (?)	
Loose blocks of heavy white sandstone, possibly of Rockwood age	——
Upper Ordovician:	
Bays sandstone.	
Clayey, unfossiliferous red, yellow, and blue shales and shaly limestone	75
Nodular blue earthy limestone holding many ramose bryozoa and *Hebertella sinuata*	40
Irregularly stratified blue limestone and shale full of *Hebertella sinuata* and *Orthorhynchula linneyi*	50
Red and yellow clayey limestone and limy shales	100
Olive shales with numerous limestone seams	90
Subgranular bluish limestone in layers ranging from 2 inches to 3 feet in thickness	70
Sevier shale.	
Olive and yellowish shales with seams of limestone in the lower part. Fossils not very abundant, but *Rafinesquina alternata* (Eden variety), *R. squamula*, *Calymene* and *Zygospira* are found	300
Middle Ordovician:	
Chickamauga limestone.	
Division 5.	
Subgranular grayish blue limestone and yellowish shales holding *Tetradium fibratum*, *Constellaria teres*, and other fossils	43
Fine-grained light gray, thin-bedded limestone with shaly partings. Fossils mainly gastropoda, silicified	73
Division 4.	
Granular blue limestone in layers varying from 2 inches to 3 feet in thickness	50
Alternating layers of granular and fine-grained limestone, thin-bedded in the upper half, massive in lower part	200

Division 3.	
Yellowish to light chocolate-colored shales with occasional thin layers of crystalline limestone holding *Dalmanella fertilis, Mesotrypa quebecensis, Heterorthis clytie,* etc.	150
Division 2.	
Yellow clayey limestone with few fossils, *Leperditella tumida* being most abundant	100
Finely granular thin white clayey limestone. Fossils numerous	50
Shales and shaly limestone with few fossils	200
Fairly pure subgranular light-colored and dove limestone	50
Division 1.	
Dove limestone, thin-bedded in upper part, massive and compact in lower	350+
Lower Ordovician:	
Knox dolomite.	
Massive magnesian limestone	——

The section along the northwest slope of Wallen ridge is essentially the same as that shown along the western side of Powell valley. A combination of the above sections therefore gives a fair idea of the Ordovician rocks in this area. From an economic standpoint the principal feature is the preponderance of limestone over shale and sandstone. In the areas further east, the Sevier shale contains little material of economic importance. Here the strata equivalent in age to this series contain more horizons of more or less pure and argillaceous limestone, although shales still make up a fair proportion of the rocks. The Bays sandstone of more eastern localities is likewise here represented by more calcareous strata, while the Middle Ordovician portion of the section mapped by the U. S. Geological Survey as the Chickamauga limestone is composed of over 1,000 feet of limestone.

In view of the great abundance of cement materials in the Chickamauga limestone, little attention was devoted to the Knox dolomite in the Powell valley area.

Chickamauga limestone.—The following notes upon the paleontology and lithology of the various formations included under the Chickamauga limestone are introduced to aid in the recognition of the strata. These formations are denoted in ascending order as divisions 1 to 5.

Division 1, massive dove limestone.—Although the rocks of this division are fairly well shown in the vicinity of Pennington Gap and Ben Hur, they are so much faulted that the succession is difficult to trace. Fossils are of little assistance since they are few and difficult to collect because of the commonly vertical attitude of the strata. At other localities studied the full succession of this formation was not exposed. The correlation of these massive dove limestones with the Stones River formation has been noted on another page.

In central Tennessee, the type area of the Stones River formation, Prof. J. M. Safford instituted the following divisions:[a]

Section Stones River formation, central Tennessee.

		Maximum thickness in feet.
5.	Carters creek limestone (now shortened to Carters). Heavy-bedded dove-colored limestone	100
4.	Lebanon limestone. Dove thin-bedded, flaggy limestone	120
3.	Ridley limestone. Heavy-bedded light blue to dove limestone	95
2.	Pierce limestone. Thin-bedded flaggy limestone and shales abounding in bryozoa	27
1.	Murfreesboro limestone. Thick-bedded light blue to dove cherty limestone	100

Sections in east Tennessee, west of the Wallen valley fault, have shown representatives of these various divisions of the Stones River, but in Virginia, with present knowledge, the correlation is made with less certainty. Dr. E. O. Ulrich made the following section and correlation of these rocks in the vicinity of Pennington Gap.

Detailed section of division 1, Chickamauga limestone, vicinity of Pennington Gap, Va.

	Thickness in feet.
Division 2.	
Dove limestone holding *Tetradium cellulosum*	——
Division 1.	
Mostly thin-bedded dove limestone weathering in part shaly. Characteristic Lebanon bryozoa in middle part	85
Finely granular, bluish dove or gray-colored limestone. (Probably equivalent of Ridley limestone of central Tennessee.)	40
Red shaly limestone. (Probably equivalent of Pierce limestone of central Tennessee.)	15
Compact dove limestone (50 feet) at top with less compact yet fine-grained light gray limestone beneath to top of Knox chert. A cherty bed in lower half 50 feet or more above base. (Equivalent of Murfreesboro limestone of central Tennessee.)	200+
Knox dolomite	——

Division 2, thin-bedded shaly and dove limestone.—The well known Birdseye (Lowville) limestone of New York has lately been recognized in the Ordovician section of central Kentucky where the name Tyrone has been applied to it. Here it consists of gray, light-drab or dove-colored limestones and shales with the fauna noted below. Along the eastern edge of the central basin of Tennessee, the same strata are well developed. Here they rest upon the Lebanon limestone and are followed by the Hermitage formation of shales and argillaceous limestone. The strata in

[a] Geology of Tennessee, 1869, pp. 258, 259.

EXPLANATION OF PLATE XXIII.

(Figs. 1–14 of natural size unless otherwise marked.)

Figs. 1–3.—*Cyrtodonta huronensis* (Billings).

1, 2. Views of an entire specimen of this pelecypod.

3. Hinge of a right valve.

Fig. 4.—*Hormotoma gracilis angustata* (Hall.) An incomplete example of this narrow gastropod.

Fig. 5.—*Subulites regularis* (Ulrich and Scofield). A nearly complete specimen of this fine shell.

Figs. 6–8.—*Phyllodictya frondosa* (Ulrich).

6. A nearly perfect specimen of this bryozoan.

7. Surface of a well preserved example, × 18.

8. A thin section, × 18, parallel to the surface, showing the minute structure of the cells.

Figs. 9–11.—*Rhinidictya nicholsoni* (Ulrich).

9. A narrow example of this ribbon-like bryozoan.

10. Surface of the same specimen, × 18.

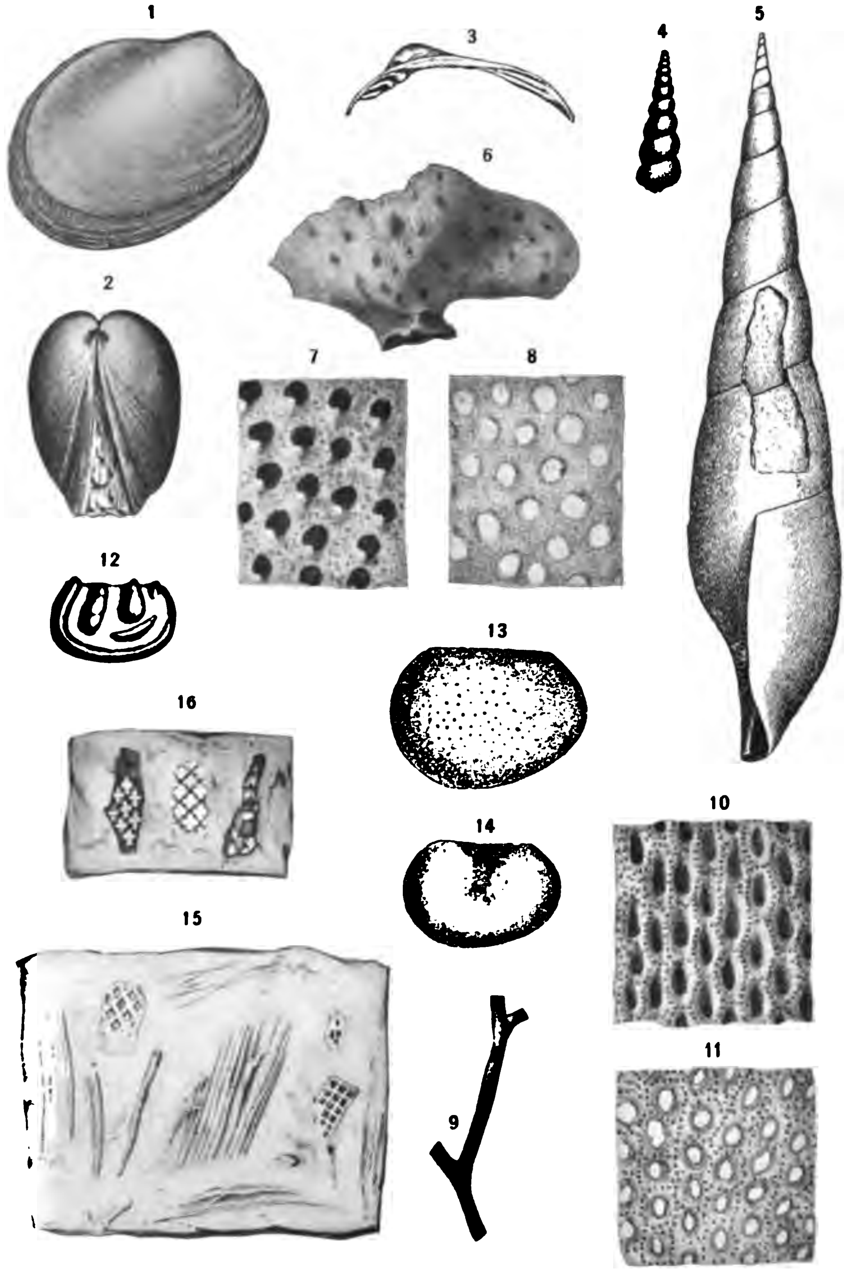
11. Tangential section, × 18, showing numerous minute granules surrounding the cells.

Fig. 12.—*Drepanella crassinoda* (Ulrich). Side view of a right valve of this well marked ostracod, × 10.

Fig. 13.—*Leperditella tumida* (Ulrich). Right valve, × 10, of this abundant form.

Fig. 14.—*Leperditella sulcata* (Ulrich). Right valve, × 10.
These views are of specimens from High Bridge, Ky., figured by Ulrich. The Virginia examples agree in every respect.

Figs. 15, 16.—*Tetradium cellulosum* (Hall). Two views showing both transverse and longitudinal sections of specimens in the rock. Upon close examination the four-lobed appearance of the individual cells becomes apparent. (After Hall.)



CHARACTERISTIC FOSSILS OF THE TYRONE FORMATION.

the Powell valley area of Virginia referred to as division 2 of the Chickamauga limestone are so similar in lithologic and paleontologic characteristics that there can be but little question that they are simply the eastward extension of the Kentucky and central Tennessee Tyrone rocks. The fossils in the three localities are identical and the rock itself is practically alike in each.

Good exposures of these strata are found along the Louisville and Nashville railroad in the vicinity of Pennington Gap and Ben Hur, Va. Reference to the general section of this particular region on page 251 shows that the formation is made up almost entirely of light-colored clayey limestones averaging comparatively high in calcium carbonate. Some of the layers show well marked sun cracks, indicating the probable tidal-flat origin of the deposits. Other layers again are covered with fucoidal markings.

As a rule, fossils are not abundant in the Tyrone, but some of the layers are fairly crowded with them. Minute ostracods of the genera *Leperditella* and *Drepanella* are most abundant. The narrow, ribbon-like, bifoliate bryozoa, *Rhinidictya nicholsoni* Ulrich, and the broader species *Phyllodictya frondosa* Ulrich, are also particularly abundant and characteristic. The coral *Tetradium cellulosum,* whose tubes of calcite scattered through the solid matrix early gave rise to the name Birdseye limestone, is likewise abundant and highly characteristic. These and other fossils which will aid in the identification of the rocks are figured in plate XXIII. All of these species have been found in the Powell river valley outcrops.

Division 3, yellow- and dark-colored shales.—Strata containing the same fossils afforded by the shales of division 3 were first described as the Hermitage formation in the Columbia folio of the U. S. Geological Survey, the name being derived from Hermitage station, Davidson county, Tennessee. In central Tennessee and Kentucky the rocks are usually thin-bedded siliceous to argillaceous limestone and shale which are in marked contrast to the dove-colored (Stones River and Tyrone) formations below and the massive blue (Bigby) limestone above. The formation becomes more shaly on the eastern side of the central basin of Tennessee, where 80 to 100 feet of strata are developed. Passing under the Appalachian coal field, the shale content still increases apparently, for in the extreme southwest corner of Virginia only occasional thin layers of limestone are found in a thickness of 150 feet of the strata here correlated with the Hermitage.

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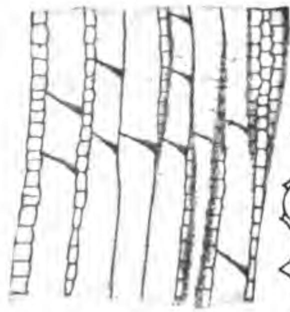

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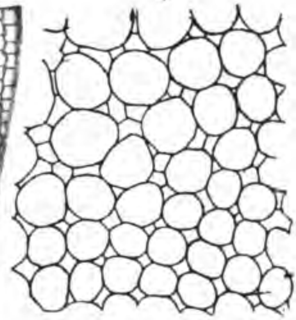

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Fig. 1.—View, natural size, of the thin, rather flat, finely lined brachiopod *Heterorthis clytie*.

Fig. 2.—Another brachiopod, *Dinorthis pectinella*, distinguished by its biconvex shape and coarse surface ribs.

Figs. 3, 4.—Ventral and tangential views, × 20, of the bryozoan *Mesotrypa quebecensis*. This fossil occurs as a solid, flat, or hemispheric mass made up of small tubes which, when magnified, give the aspect here figured.

Fig. 5.—Portion of surface of thin limestone from division 3 of Chickamauga limestone at Pennington, Va. The numerous brachiopod shells, *Orthis* (*Dalmanella*) *testudinaria*, early give rise to the name Orthis bed, for the formation in central Tennessee.

CHARACTERISTIC FOSSILS OF THE HERMITAGE SHALE (DIVISION 3 OF THE CHICKAMAUGA LIMESTONE).

A small brachiopod, *Orthis (Dalmanella) fertilis* Ulrich, is so abundant in the Hermitage formation that it caused Professor Safford to apply the name Orthis bed to these rocks. In Virginia this brachiopod, although still characteristic, is not quite so abundant. Other diagnostic fossils are the discoid bryozoa, *Mesotrypa quebecensis,* the hat-shaped form *Prasopora simulatrix,* and the flat, thin brachiopod, *Hebertella clytie.*

As a source of cement material the limestone of division 3 is too siliceous and sparingly developed, but the shales are shown to be of value in mixture by the following analysis:

Analysis of shale of division 3, Chickamauga limestone, Ben Hur, Va.

(Wm. M. Thornton, Jr., Analyst.)

	Per cent.
Insoluble (SiO_2)	68.88
Alumina (Al_2O_3)	14.28
Iron oxide (Fe_2O_3)	6.02
Magnesia (MgO)	1.75
Lime (CaO)	0.11
Manganese oxide (MnO)	0.16
Loss on ignition	6.08
Total	97.28

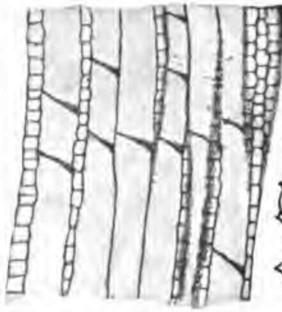
The formation as a whole is seldom well shown in natural exposures in Virginia, the view at Ben Hur, reproduced on plate XXV, being the best known.

Division 4, granular blue limestone.—Two hundred and fifty feet or less of rather massive, granular blue limestone succeed the yellowish shales of the preceding division in the area under discussion. In texture these strata vary from fine- to coarse-grained, but in chemical composition as a whole they are probably the most uniform of the entire Ordovician. Their value is thus increased accordingly. Some of the layers are laminated similarly to the equivalent rocks in central Tennessee, but no evidence of phosphatic material so characteristic of the central Tennessee area was observed at the Virginia localities. In the section northwest of Powell mountain, only 80 feet of division 4 were noted. It is possible that with more study a portion of the overlying strata will be referred to this division, thus bringing the thickness nearer to that prevailing along the western side of Powell valley.

These strata run high in lime, silica being the main impurity, as shown in the following analysis. Upon weathering this silica becomes evident in the fossils which appear at the surface as siliceous pseudomorphs.

1

3



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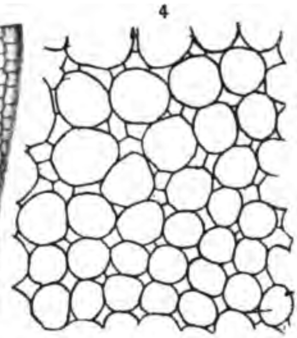


2

5

Fig. 1.—View, natural size, of the thin, rather flat, finely lined brachiopod *Heterorthis clytic.*

Fig. 2.—Another brachiopod, *Dinorthis pectinella*, distinguished by its biconvex shape and coarse surface ribs.

Figs. 3, 4.—Ventral and tangential views, × 20, of the bryozoan *Mesotrypa quebecensis.* This fossil occurs as a solid, flat, or hemispheric mass made up of small tubes which, when magnified, give the aspect here figured.

Fig. 5.—Portion of surface of thin limestone from division 3 of Chickamauga limestone at Pennington, Va. The numerous brachiopod shells, *Orthis* (*Dalmanella*) *fertilis*, early give rise to the name Orthis bed, for the formation in central Tennessee.

CHARACTERISTIC FOSSILS OF THE HERMITAGE SHALE (DIVISION 3 OF THE CHICKAMAUGA LIMESTONE).

Analysis of Chickamauga limestone, division 4, Ben Hur, Va.

	I.	II.	III.	IV.
	Per cent.	Per cent.	Per cent.	Per cent.
Insoluble	8.56	1.22	6.93	5.40
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3) }	1.68	1.53	1.94	2.20
Lime (CaO)	50.28	——	49.11	48.70
Calcium carbonate $(CaCO_3)$	89.48	84.07	87.69	86.96
Magnesia (MgO)	0.08	——	1.36	2.42
Magnesium carbonate $(MgCO_3)$	0.17	2.01	2.86	5.06
Total	99.89	88.83	99.42	99.62

I. J. H. Gibboney, analyst.
II, III and IV. Wm. M. Thornton, Jr., analyst.

The correlation of the granular blue limestones composing division 4 with the Bigby limestone of central Tennessee has been noted.

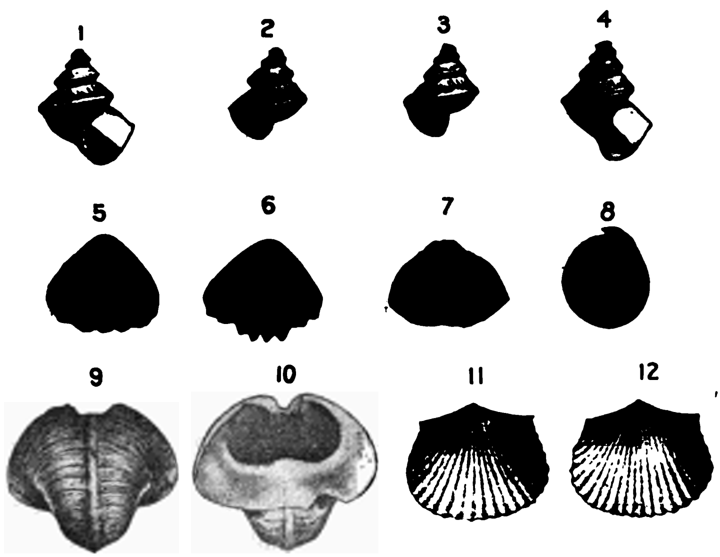


Fig. 20—Fossils of Bigby limestone.

Nos. 1–4.—Four individuals of the gastropod *Lophospira medialis* (Ulrich); 5–8. Four views of a rather large example of the brachiopod *Rhynchotrema increbescens* (Hall); 9–10. Opposite sides of the gastropod *Bellerophon troosti* (D'Orbigny); 11–12. Opposite sides of the brachiopod *Hebertella borealis* (Billings). Views are natural size, and are after Ulrich and Nettelroth.

A few of the more common and conspicuous fossils of the Bigby limestones are figured above. The two brachiopods, *Rhynchotrema*

increbescens (Hall) and *Hebertella borealis* (Billings), as well as the gastropods *Bellerophon troosti* (Safford) and *Lophospira medialis* (Ulrich and Scofield), are quite common, especially in the siliceous residue left by the weathering of the limestone. Among the bryozoa with which some of the strata are crowded, the cylindrical, seldom branching stems of *Constellaria teres* (Ulrich and Bassler) are very abundant. This form may be recognized by the regularly placed star-shaped spots or monticules of its surface. Under a hand lens these spots are seen to be made up of cells more minute than those of the rest of the surface. These particular fossils as well as other characteristic Bigby species occur in abundance in southwesternmost Virginia.

Fig. 21.—Fossils of the Cathey limestone. Natural size view of the characteristic gastropod *Cyclonema varicosum* (Hall); and view of cross section, × 2, of the coral *Tetradium fibratum* (Safford).

Division 5, thin blue limestone and interbedded yellow shale.—The rather massive blue limestone of division 4 is succeeded in the Powell valley area by thin-bedded, lighter colored limestones and shales identical in faunal and lithological characters with the central Tennessee formation termed Cathey limestone by Hayes and Ulrich.[a] These strata are particularly well exposed in the railroad cuts at Ben Hur, where the best opportunity is afforded for also studying their fossils. The lithology is sufficiently distinct from the associated formations to prevent confusion, so that only a few of the characteristic fossils are figured. The gastropod *Cyclonema varicosum* (Hall) is probably the most striking fossil of the formation, although masses of the coral *Tetradium fibratum* (Safford) are not uncommon. A third fossil, the brachiopod *Orthorhynchula linneyi* (James), is abundant but is not strictly diagnostic of these strata since it is found in equal abundance in the higher Bays sandstone.

As indicated in the section on page 177, the rocks of division 5 are in general thin-bedded limestone with shaly partings, probably averaging 100 feet in thickness. This alternation of thin limestones and shales causes

[a]U. S. Geological Survey, Folio No. 95, 1903.

Fig. 1.—A characteristic exposure of the shale composing division 3 at Ben Hur, Va. The soft shales of this formation have weathered into clays, leaving only an occasional thin limestone band outcropping in the gullies. In the railroad cut just beyond is an exposure of limestone (division 4), while Cumberland mountain in the distance is made up of Devonian to Pennsylvania strata.

Fig. 2.—Contorted strata in the Chickamauga limestone (division 4), railroad cut, near Ben Hur, Va.

OUTCROPS OF DIVISIONS 3 AND 4 OF THE CHICKAMAUGA LIMESTONE.

this division to be the least important one of the Chickamauga limestone as a source of cement materials, since a uniform composition cannot be depended upon. The analyses of materials from division 5, in tabular form, are as follows:

Analyses of Chickamauga limestone, division 5, Ben Hur, Va.

(Wm. M. Thornton, Jr., Analyst.)

	I.	II.	III.	IV.	V.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Insoluble	14.00	8.38	7.76	2.69	11.97
Alumina (Al_2O_3), Iron oxide (Fe_2O_3)	2.36	3.61	2.88	1.28	4.54
Lime (CaO)	36.40	——	48.40	50.13	43.61
Calcium carbonate ($CaCO_3$)	82.86	85.60	86.43	89.51	77.87
Magnesia (MgO)	0.05	——	1.11	2.25	0.87
Magnesium carbonate ($MgCO_3$)	0.11	1.80	2.31	4.70	1.84
Total	99.33	99.39	99.38	98.18	96.02

Upper Ordovician Strata.

In a previous paper[a] the writer has correlated the basal Upper Ordovician shales of Powell valley with the Utica slate of New York, basing this inference mainly upon the occurrence of the trilobite *Triarthrus becki* in strata occupying apparently the same horizon elsewhere in Virginia. A further study of the area seems to indicate that, as in central Kentucky, all of the olive and yellow shales succeeding the last division of the Chickamauga limestone are referable to the Eden shale of Ohio. This view is strengthened by the fossils, which, although rather uncommon, are clearly of Eden species. The branching bryozoan, *Callopora sigillarioides,* and the several brachiopods figured on plate XIV, are the most abundant forms in Virginia. The unconformable relation of this shale and the Chickamauga limestone is represented in the view of the railroad cut at Ben Hur (plate XXVI) where the shale is seen to rest upon the uneven surface of the thin-bedded limestone.

In the Powell valley area the U. S. Geological Survey has mapped this shale, of Eden age, as the Sevier shale. Farther east in the Appalachian district the Sevier shale includes strata of greater age.

The upper portion of the Sevier shale contains so much sandy material that a few of the layers approach sandstones in composition. A considerable

[a]Mineral Resources of Virginia, 1907, p. 150.

amount of siliceous matter is present in the lower part also, so, as a whole, the Sevier cannot be regarded as of much value as a cement material. Some of the shales are of the more argillaceous type, but their thickness is small and their composition probably not uniform.

Subgranular blue limestones and earthy limestones, with shales of various colors holding characteristic fossils of the lower half of the Maysville formation of the Ohio Valley, succeed the arenaceous Sevier shale in westernmost Virginia. These strata have hitherto been correlated by the writer with the Lorraine formation of the New York scale, and the practice has been adhered to in the present work, even in view of some uncertainty regarding the exact correlation of the Lorraine and Maysville. The Maysville formation was proposed by Foerste to replace the Cincinnatian strata referred to the Lorraine. The matter of nomenclature is complicated by the fact that the Virginia rocks can be correlated directly with the Leipers formation of central Tennessee as instituted by Hayes and Ulrich.[a] This same name was proposed by Foerste a short time before the publication of the Columbia folio (No. 95) for Tennessee rocks, mainly of Richmond age. The fossils of the Virginia strata indicate their equivalence with only the Mt. Hope and Fairmount members of the Cincinnati section, for which the present writer has published the formational name of Fairview. In view of the above, it might be well to apply this name to the Virginia strata to call attention to the similarity of the Powell valley section with that of the Ohio Valley, but an earlier name—the Bays sandstone—has been adopted in the Appalachians for the more eastern sandy phase of the same rocks.

The most important feature of the Powell valley Bays strata, from an economic standpoint, is their lithologic resemblance to the Ohio Valley strata of the same age. In both of these areas sandy strata are little developed, clayey and purer limestones and shales occupying this horizon. The possible value of the strata is thus apparent and is in contrast with the useless sandy shales and sandstones of the Bays formation in the more eastern parts of the Appalachians.

DISCUSSION OF INDIVIDUAL COUNTIES.

GILES COUNTY.

The portion of Giles county occupied by Ordovician strata is so large compared with most other counties of southwestern Virginia that a special map based upon a manuscript map by Mr. M. R. Campbell of the U. S.

[a] U. S. Geological Survey, Folio No. 95, 1903.

Fig. 1.—View of Lorraine (Bays) shales and thin limestones along Louisville and Nashville railroad east of Ben Hur, Va.

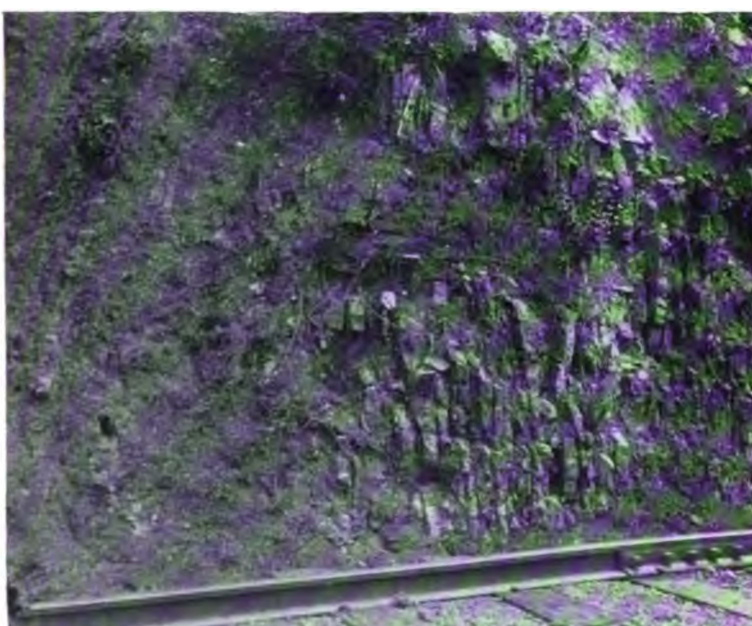


Fig. 2.—View illustrating unconformity between Chickamauga limestone and Sevier shale. The shales rest upon the uneven surface of the thin-bedded limestone. Railroad cut near Ben Hur, Va.

OUTCROPS OF ORDOVICIAN FORMATIONS IN SOUTHWEST VIRGINIA.

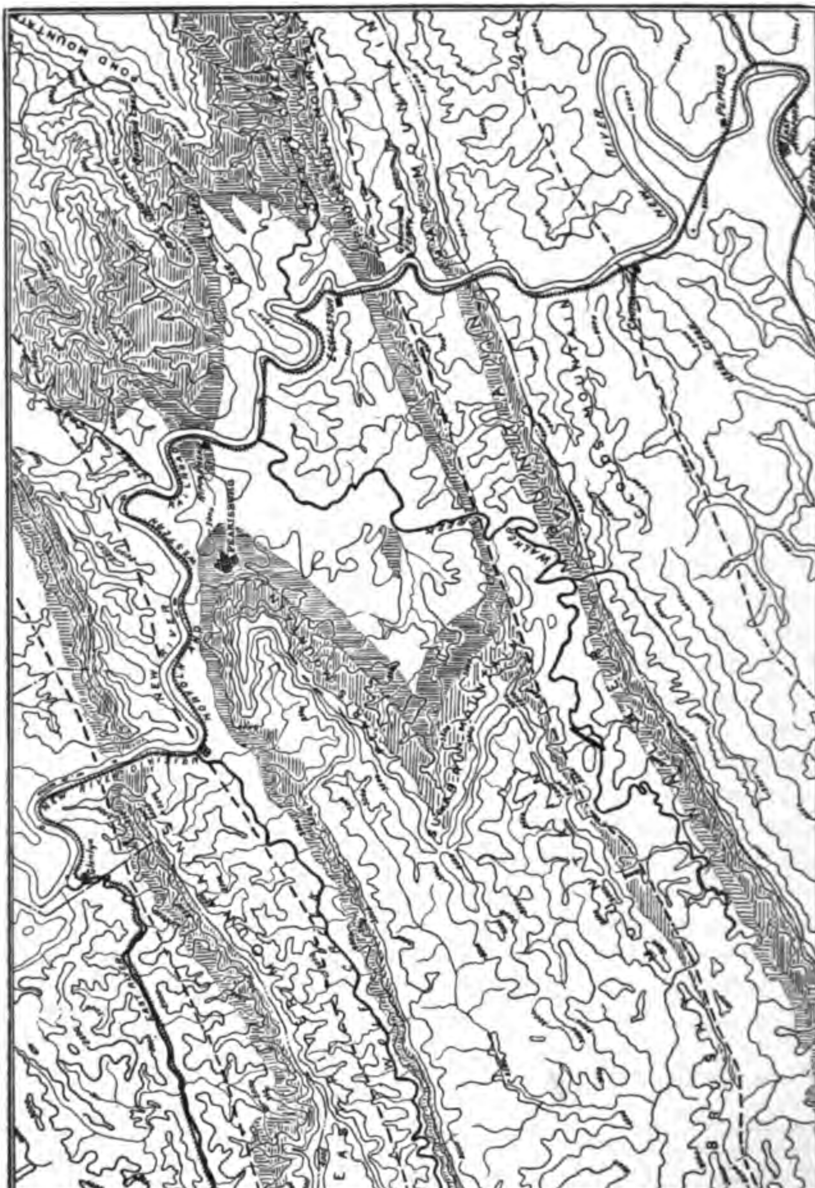
Geological Survey has been introduced. As indicated on this map, four areas of these limestones and shales are present. These are, commencing in the northwestern part of the county, (1) a strip just northwest of East river and Peters mountains, (2) a fold encircling Pearis and associated mountains west of New river and the corresponding mountains east of the river, (3) a band following the northern slope of Buckeye and Spruce Run mountains, and (4) a narrow band occupying the same slope of Walker mountain. In each of these areas, the succession of strata between the Knox dolomite and the Moccasin limestone is slightly different, so that sections and samples for analysis were selected with special reference to these localities. The first is discussed under the heading of the Narrows section, the second under Pearisburg and Ripplemead, the third as the Eggleston section, and the fourth as the Goodwin Ferry section.

Giles county has an abundance of limestones of favorable composition and fairly well situated for either lime or cement purposes. The best rock belongs to the Chickamauga limestone, sections of which are given in detail on later pages. Each of the four areas mentioned above contains a representative of this limestone, and each, furthermore, is crossed by a railroad.

Narrows section.—About a mile north of this station the northernmost belt of Ordovician rocks in Giles county occurs, with the strata dipping northeastwardly. The highest member, the Clinch, forms the crest of East River mountain at this point; proceeding northward the lower formations are met in descending order until the Knox dolomite is found faulted against the Devonian shales and sandstones. It will be noted that the stratigraphy of this belt is essentially the same as that of the Five Oaks and other sections in Tazewell county, given on another page, but less favorable exposures prevented the making of as detailed a section. Samples for analysis were collected only from the various portions of the Chickamauga limestone, the remaining formations being of little economic importance. This formation consists essentially of 500 feet of bluish gray limestone at the top, preceded by massive dove limestones and an earthy conglomeratic stratum at the base, making altogether a thickness of about 600 feet. This section is as follows, the formations being numbered as in the structure section (figure 23) of the same area:

Ordovician strata exposed in section between Narrows and Lurich, Va.

		Feet.
5.	**Bays sandstone:**	
	Red sandstone and shale	——
4.	**Sevier shale:**	
	Olive, blue, and brown shales	——



Ordovician limestones

Ordovician shales

Fig. 22.—Map showing distribution of cement materials of the New River district, southwestern Virginia.

3. Moccasin limestone:	
Red, argillaceous limestone	——
2. Chickamauga limestone:	
Bluish gray, cobbly limestone, poorly exposed, free from chert, about	500
Massive, rather compact dove limestone	30
Limestone mainly, no outcrop	63
Earthy magnesian limestone with pebbles of chert in lower part	8
1. Upper Knox (Beekmantown) dolomite:	
Thin-bedded, fine-grained, bluish gray sublaminar limestone	68
Medium- to fine-grained bluish gray, even-bedded, magnesian limestone with little chert	260
Magnesian limestone with thin bands of chert	20
Heavy-bedded, fine-grained, magnesian limestone	60
Fine-grained limestone low in magnesia, with black flint and chert at the top and bottom	20
Rather massive grayish fine-grained magnesian limestone with no chert	160
8. Devonian sandstone and shale	——

The general stratigraphic relations along New river in the northernmost belt of Chickamauga limestone is indicated in figure 23.

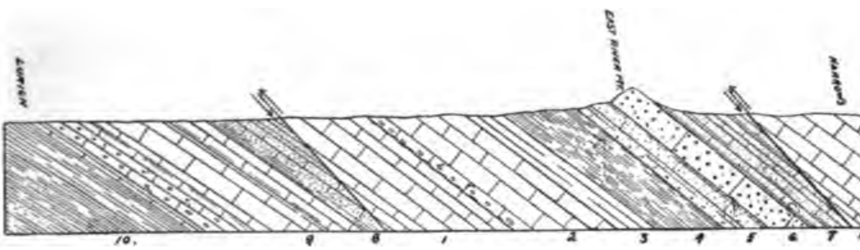


Fig. 23.—Structure section along New river between Narrows and Lurich, Va. I. Upper Knox (Beekmantown) magnesian limestone. 2. Chickamauga limestone. Bluish to dove, more or less pure limestone. 3. Moccasin limestone. Blue to yellow, calcareous to sandy shale. 5. Bays sandstone. Red sandstone and sandy shale. 6. Clinch sandstone. Coarse white sandstone. 7. Sandstones and shales. 8. Upper Devonian and Lower Mississippian sandstone and sandy shale. 9. Mississippian (Greenbrier) limestone. 10. Mississippian shale.

The samples selected from various horizons of the Chickamauga limestone in this section show a rather uniform chemical composition. The high lime content of these strata is indicative of their use in other parts of the county.

Analyses of Chickamauga limestone, vicinity of Narrows, Va.

(J. H. Gibboney, Analyst.)

	I.	II.	III.
	Per cent.	Per cent.	Per cent.
Insoluble	5.60	1.50	2.30
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3) }	0.78	0.58	0.60
Lime (CaO)	51.40	54.76	54.06
Calcium carbonate ($CaCO_3$)	91.80	97.78	96.54
Magnesia (MgO)	0.72	0.15	0.30
Magnesium carbonate ($MgCO_3$)	1.52	0.31	0.64
Total	99.70	100.17	100.08

I. Compact, massive, dove limestone from lower portion of formation.
II. Thin-bedded blue limestone from middle portion of formation.
III. Dove-colored compact limestone from upper part of formation.

Samples of limestone from the Knox dolomite of this area were analyzed under the direction of Professor Rogers. The results are as follows:

Analyses of Knox dolomite, Giles county, Virginia.

	I.	II.
	Per cent.	Per cent.
Calcium carbonate ($CaCO_3$)	13.23	11.17
Magnesium carbonate ($MgCO_3$)	10.99	8.31
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	0.14	1.06
Silica (SiO_2)	0.55	4.27
Water	0.09	0.19

I. Light gray limestone from near the mouth of Wolf creek, Giles county.
II. Greenish gray, compact limestone from gap of Peter's mountain, north side of New river, 4 miles from Gray Sulphur springs.

Pearisburg section.—In the second area of Chickamauga limestone a well exposed detailed section is presented at Pearisburg. The section, which is repeated below from a previous page, commences in the Knox strata east of Pearisburg, extends through the town and up the slope of Pearis mountain:

Geologic section, Pearisburg, Va.

	Feet.
4. Sevier shale	——
3. Moccasin limestone:	
Purple calcareous shales and argillaceous limestone with seams of impure dove limestone	200+
2. Chickamauga limestone:	
(f) Light gray compact limestone with gastropods abundant in the lower beds and numerous ostracoda in the upper part	60
(e) Fine-grained dove limestone	20
(d) Thin-bedded magnesian limestone	25
(c) Light to dark gray, moderately fine-grained limestone in lower part and massive cherty beds in upper division	65
(b) Dark bluish-gray limestone, subcrystalline or earthy in the upper part and slightly cherty in the lower beds. A species of *Girvanella*, less than ½ inch in diameter, very abundant	50
(a) Dark gray mottled limestone leaving deep red chert upon weathering. Fossils numerous, bryozoa, brachiopods, and *Solenopora* being particularly abundant	250
1. Knox dolomite:	
Magnesian limestone weathering into reddish chert	——

1. *Knox dolomite.*—Rocky soils of a red color holding chert fragments but with no prominent limestone outcrops characterizing the area underlaid

by Knox. In exposures along the railroads and river where more or less unweathered rock can be seen, the strata have their usual dull gray appearance. No samples were collected by the writer for analysis, since all of the field tests indicated that the Knox of this area contained its usual high percentage of magnesia. The magnesian limestones of Giles county were studied and analyzed for Professor Rogers with a view to their use as hydraulic cement rocks. The results of these analyses are as follows:

Analyses of magnesian limestones of Giles county, Virginia.

	I.	II.	III.	IV.
	Per cent.	Per cent.	Per cent.	Per cent.
Calcium carbonate ($CaCO_3$)	14.71	14.90	13.28	16.08
Magnesium carbonate ($MgCO_3$)	7.47	7.70	10.73	13.10
Silica (SiO_2)	5.17	4.63	5.19	0.50
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	1.71	2.50	0.60	0.14
Water	0.22	0.20	0.10	0.09
Loss	0.72	0.07	0.10	0.09
Total	30.00	30.00	30.00	30.00

I. Reddish brown, slightly granular limestone from Pack's mill, New river.
II. Light gray limestone from same locality.
III. Gray, granular limestone from Chapman's ferry, New river, Giles county.
IV. Dark gray, granular limestone from New river, a little below Chapman's ferry.

2. *Chickamauga limestone.*—The limestone formation occupying the interval between the Knox and Moccasin limestones hold a fauna the exact age of which has not yet been determined. However, it seems probable that these rocks are of Stones River and Lowville (Tyrone) age, since the lowest beds of the overlying Moccasin limestone have yielded Trenton fossils. The fossils of some of the beds have a resemblance to those of the Chazy, and it is possible that more careful correcting and study will bring out this correlation. The following lithologic divisions were recognized in this limestone at Pearisburg:

(a) The greater portion of this division is of dark gray massive limestone, but portions are dark blue in color and weather into red chert. The difference in composition of these two grades of rock is indicated in the analyses. In tracing this limestone by its residual chert, care must be exercised not to confound it with the similar chert resulting from the weathering of the Knox dolomite. The chert of the Chickamauga limestone is usually black inside and laminated horizontally, and of a deeper red color

and smoother on the surface than that of the Knox. Fossils are numerous in the chert of the higher beds while they are practically wanting in the Knox.

Analyses of limestone, bed 2a, Pearisburg section.

(J. H. Gibboney, Analyst.)

	I.	II.
	Per cent.	Per cent.
Insoluble	6.14	7.86
Organic matter	0.26	——
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	0.94	0.90
Lime (CaO)	50.30	48.00
Calcium carbonate ($CaCO_3$)	89.82	85.72
Magnesia (MgO)	1.57	2.85
Magnesium carbonate ($MgCO_3$)	3.30	6.00
Total	100.46	100.48

I. Dark gray limestone.
II. Dark blue limestone weathering into chert.

(b) Fifty feet of dark bluish gray limestone, in which the small concretionary-like fossil *Girvanella* is practically abundant, follow the more massive limestone of the preceding member. Subcrystalline and earthy strata make up the upper thirty feet, while the lower portion is rather massive and slightly cherty. The subcrystalline beds of the upper part gave the following analysis:

Analysis of subcrystalline limestone, bed 2b, Pearisburg section.

(J. H. Gibboney, Analyst.)

	Per cent.
Insoluble	5.02
Organic matter	0.43
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	1.00
Lime (CaO)	51.36
Calcium carbonate ($CaCO_3$)	91.71
Magnesia (MgO)	1.24
Magnesium carbonate ($MgCO_3$)	2.60
Total	99.76

(c) The 300 feet of strata comprising beds *a* and *b* are exposed in the Pearisburg section mainly east of the village. The following divisions are found outcropping in order ascending the foothills of Pearis mountain. Bed *c* is composed of light and dark gray rather fine-grained, massive limestone, earthy in the lower part but slightly cherty toward the top. These

make up a thickness of 65 feet, of which the greater part is of the grayish colored limestone. Analyses of different portions of these beds show an unusual similarity of composition.

Analyses of fine-grained limestone, bed 2c, Pearisburg section.

(J. H. Gibboney, Analyst.)

	I.	II.
	Per cent.	Per cent.
Insoluble	3.88	3.14
Alumina (Al_2O_3), Iron oxide (Fe_2O_3)	0.50	1.58
Lime (CaO)	52.00	51.60
Calcium carbonate ($CaCO_3$)	92.84	92.14
Magnesia (MgO)	1.43	1.54
Magnesium carbonate ($MgCO_3$)	3.00	3.23
Total	99.22	100.09

I. Light gray, massive limestone.
II. Dark, massive limestone.

(d) The even-bedded slightly laminar, unfossiliferous magnesian limestones making up this bed are easily recognized in the field as distinct from the accompanying more calcareous strata. Their dull gray color will also serve as a means of distinction.

Analyses of laminar unfossiliferous limestones, bed 2d, Pearisburg section.

(J. H. Gibboney, Analyst.)

	I.	II.
	Per cent.	Per cent.
Insoluble	2.16	0.52
Alumina (Al_2O_3), Iron oxide (Fe_2O_3)	0.66	0.38
Lime (CaO)	50.30	51.24
Calcium carbonate ($CaCO_3$)	89.82	91.50
Magnesia (MgO)	3.62	3.66
Magnesium carbonate ($MgCO_3$)	7.60	7.68
Total	100.24	100.08

(e) Fine-grained dove strata succeed the laminar beds of the preceding member, and although only 20 feet in thickness, they can be counted upon to furnish a high grade limestone. The small amount of iron, alumina, silica, and magnesia, and the high percentage of lime are apparent in the analysis.

Analysis of fine-grained dove limestone, bed 2e, Pearisburg section.

(J. H. Gibboney, Analyst.)

	Per cent.
Insoluble	2.24
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	0.46
Lime (CaO)	53.80
Calcium carbonate ($CaCO_3$)	96.07
Magnesia (MgO)	0.48
Magnesium carbonate ($MgCO_3$)	1.00
Total	99.77

(f) The Chickamauga limestone closes with beds of light gray compact strata intermingled with darker, semi-mottled or subcrystalline rock. The upper beds contain many ostracoda which appear as minute black specks scattered through the light-colored rock. The semi-mottled layers seemed to be the least pure of these limestones, but even these run high in lime.

Analysis of semi-mottled limestone, bed 2f, Pearisburg section.

(J. H. Gibboney, Analyst.)

	Per cent.
Insoluble	6.56
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	0.64
Lime (CaO)	50.28
Calcium carbonate ($CaCO_3$)	89.78
Magnesia (MgO)	1.66
Magnesium carbonate ($MgCO_3$)	3.48
Total	100.46

3. *Moccasin limestone.*—Two samples of the red and drab-colored impure limestones, respectively, of this formation were analyzed in order to complete the section of Ordovician limestones. The outcrops of the Moccasin formation in this particular are so inaccessible that, especially with the abundant Chickamauga limestone at hand, it need not be considered as a source of cement rock.

Analyses of Moccasin limestone, Pearisburg section.

(J. H. Gibboney, Analyst.)

	I.	II.
	Per cent.	Per cent.
Insoluble	11.73	7.66
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	1.48	0.82
Lime (CaO)	47.78	50.38
Calcium carbonate ($CaCO_3$)	85.32	89.96
Magnesia (MgO)	0.24	0.35
Magnesium carbonate ($MgCO_3$)	0.58	0.76
Total	99.11	99.20

I. Impure drab limestone.
II. Red clayey limestone.

Continuing the Pearisburg section to the top of Pearis mountain the Sevier shale and the Bays, Clinch, and Rockwood sandstones are found in their usual development in this part of Virginia.

Ripplemead.—In this vicinity a syncline of about a mile in width exposes the lower beds of the Chickamauga limestone. Here the New River Lime Company has a large quarry working the rock, and analyses published by this company are quoted below. In the Pearisburg section this limestone is described as cherty, but in the freshly quarried rock no chert can be found. The chert, however, shows abundantly on long weathered surfaces or in fissures. As the analyses show, the unweathered limestone contains a percentage of silica small enough to allow the use of the rock in the manufacture of lime or cement. Therefore, as mentioned on a previous page, a limestone which shows abundant chert at the surface is not for this reason precluded from being of use in these two industries.

Analyses of massive limestone from lower part of Chickamauga formation, Ripplemead, Va.

(Dr. Henry Froehling, Analyst.)

	I.	II.	III.
	Per cent.	Per cent.	Per cent.
Silica (SiO_2)	1.17	2.12	1.35
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3) }	1.20	0.25	0.43
Calcium carbonate ($CaCO_3$)	91.85	95.03	96.04
Magnesium carbonate ($MgCO_3$)	5.52	2.40	1.75
Organic matter	0.25	0.18	0.40
Total	99.99	99.98	99.97

Crossing the New river east of Ripplemead the higher beds of the Chickamauga limestone are found in ascending order until about a mile east of this station the Moccasin limestone outcrops. East of the comparative narrow belt of the red Moccasin limestone is an area of at least three miles in width underlaid by Sevier shale. Ripplemead and its vicinity therefore has an abundance of limestones and shales of possible use for cement material.

Eggleston section.—This small area of outcrop is essentially a continuation of the Pearisburg region, but the somewhat different development of the purer limestones is shown in exposures along the Norfolk and Western railroad between Goodwin Ferry and Eggleston. This section, here selected as typical for the area, commences in the Knox dolomite at Eggleston and continues through the Sevier shale exposed at Goodwin Ferry.

Section from Eggleston southward along New river to Goodwin Ferry. Length of section, 2 miles.

	Feet.
Fault at Goodwin ferry.	
Sevier shale:	
Blue to brown and yellow shales—few outcrops	1,500
Moccasin limestone:	
Red to green and yellow, hard earthy limestone weathering into thin laminæ	400
Reddish earthy limestone with few outcrops	250
Chickamauga limestone:	
Thin-bedded, mottled reddish to greenish, fine-grained limestone with clay conglomeratic bed at the base	70
Mottled grayish-blue and reddish limestone interbedded	42
Massive finely granular, reddish limestone with a few white layers	65
Mottled, irregularly bedded limestone	70
Fine-grained limestone with numerous small spots of calcite	50
Rather massive, finely granular gray to blue limestone with occasional layers holding chert nodules in the lower part. *Maclurea* and other gastropods, *Girvanella* and *Eospongia* noted among the fossils	452
Massive dove limestone	30
Massive gray, finely granular, slightly magnesian limestone yielding much chert upon weathering	73
Dark bluish gray limestone with bands of chert nodules	90
Massive fine-grained dove limestone	135
Knox (Beekmantown) dolomite:	
Fine-grained magnesian limestone with yellowish argillaceous beds. Upper layers with small angular or rounded chert pebbles	90
Fine-grained dolomite—gray to bluish color	400

The massive fine-grained dove limestone is in all probability the best rock of this section for lime-making, and an extensive quarry in this bed was once operated at this point. The sample analyzed had the following composition:

Analysis of massive dove strata at base of Chickamauga limestone, Eggleston section, 1 mile south of Eggleston, Va.

(J. H. Gibboney, Analyst.)

	Per cent.
Insoluble	3.26
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3) }	0.34
Lime (CaO)	52.90
Calcium carbonate ($CaCO_3$)	94.46
Magnesia (MgO)	0.98
Magnesium carbonate ($MgCO_3$)	3.05
Total	100.11

Probably next in importance to this dove limestone is the massive finely granular gray to blue limestone occurring higher in the section and measuring 452 feet in thickness. An apparently average sample was selected for the analysis, which gave a lime content higher even than the basal dove

strata. The chert nodules resulting from weathering of the lower part would apparently bar the use of this rock, but it is believed these would disappear when quarrying had gone beyond the zone of weathering.

Analysis of fine-grained, dark blue limestone, Eggleston section, 1 mile south of Eggleston, Va.

(J. H. Gibboney, Analyst.)

	Per cent.
Insoluble	1.00
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	0.10
Lime (CaO)	54.88
Calcium carbonate ($CaCO_3$)	98.00
Magnesia (MgO)	0.18
Magnesium carbonate ($MgCO_3$)	0.38
Total	99.48

Goodwin Ferry section.—The coal field of the Little Walker and Cloyds mountains area is terminated on the southeast by a fault bringing the Knox dolomite in contact with Carboniferous strata. The section from this fault to the next, five or six miles north at Goodwin Ferry, is finely exposed along the New river and cuts of the Norfolk and Western railroad. About two miles south of Goodwin Ferry the Ordovician limestones and shales of this section are exposed, and for lack of a station nearer the outcrops the section is described under the above name. This, the southernmost area of Ordovician outcrops in Giles county, consists of a single strip or band of strata paralleling Walker mountain.

Section from Goodwin Ferry southward along New river to Dry Branch. Length of section about 3 miles.

	Feet.
Silurian and Devonian shales and sandstone (Dry Branch Station):	
Dark fissile shale	——
Ferruginous sandstone and yellowish sandstone and shale	200
Alternating thin sandstone and sandy shales with slightly calcareous bluish and greenish fossiliferous shale at the top	800
Clinch sandstone:	
Heavy-bedded white to red quartzites and sandstones	400
Bays sandstone:	
Reddish sandstones and shales, mostly unexposed	300
Sevier shale:	
Olive shales. *Triarthrus becki* noted in lower part	500
Blue shales with interbedded thin blue limestone containing *Plectambonites sericeus*	250
Moccasin limestone:	
(c) Reddish shales	250
(b) Light gray subcrystalline limestone interbedded with sandy and limy shales. Contains *Dalmanella testudinaria* and *Plectambonites sericeus*	75
(a) Red shaly limestone	170

Chickamauga limestone:	
(e) Thin-bedded shaly limestone, yellow and blue shales and gray marbles containing numerous fossils of which bryozoa and *Solenopora* are abundant	100
(d) Light gray, fine-grained nodular limestone, massive when freshly quarried but weathering into rough, shaly slabs	300
(c) Cherty fine-grained gray limestone	43
(b) Rather massive, finely granular gray limestone with some of the layers crowded with a small *Girvanella*	126
(a) Gray subcrystalline and crystalline limestones crowded with *Solenopora*	56
Knox (Beekmantown) dolomite:	
Rather earthy light gray laminar magnesian limestone with a few bands of small, inconspicuous chert nodules	1,300

Fault at Goodwin Ferry.—Proceeding south from the ferry, the Knox dolomite is exposed for a distance of over a mile. The rock here has the usual gray magnesian aspect, but 700 to 800 feet below the top, sandy layers were observed. Following these were a few dove-colored strata interbedded with the usual dolomite. As may be noted from the analyses, these sandy layers gave less insoluble material than would be expected, while the dove-colored rock is unusually high in lime and low in magnesia. The composition of these limestones is exceptional, the main mass of the rock being more magnesian.

Analyses of limestones, Knox dolomite, Goodwin Ferry section.

(J. H. Gibboney, Analyst.)

	I.	II.
	Per cent.	Per cent.
Insoluble	1.38	24.54
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	2.88	3.66
Lime (CaO)	52.48	39.20
Calcium carbonate ($CaCO_3$)	93.71	70.00
Magnesia (MgO)	0.67	0.62
Magnesium carbonate ($MgCO_3$)	1.41	1.31
Total	99.38	99.51

I. Dove-colored limestone.
II. Arenaceous limestone, 800 feet below top of formation.

The Chickamauga limestone follows the Knox dolomite with little evidence of an unconformity, although if these strata are correctly identified a great time break exists between them and the Knox. This unconformity is no doubt in part represented by the chert bands described in the section. In ascending order, going southward, the various divisions of the Chicka-

mauga limestone may be observed well exposed along the railroad. The analyses have been tabulated with reference to the notation of beds in the section.

Analyses of Chickamauga limestone, Goodwin Ferry section.

(J. H. Gibboney, Analyst.)

	I.	II.	III.	IV.
	Per cent.	Per cent.	Per cent.	Per cent.
Insoluble	0.98	6.64	6.04	1.42
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	0.68	0.80	0.84	0.26
Lime (CaO)	54.88	50.80	51.20	54.84
Calcium carbonate ($CaCO_3$)	98.00	90.71	91.43	97.93
Magnesia (MgO)	0.20	1.04	0.80	0.11
Magnesium carbonate ($MgCO_3$)	0.43	2.18	1.67	0.23
Total	100.09	100.33	99.98	99.84

I. Coarsely crystalline gray limestone, bed *a*.
II. Compact dark argillaceous limestone, bed *b*.
III. Dark argillaceous limestone, lower part of bed *d*.
IV. Marble, base of bed *e*.

The red and drab earthy limestones of the Moccasin formation are well exposed in the particular section under discussion. The more calcareous portions here adjoin the Chickamauga strata, and the following analysis was of a sample collected in the lowest layer:

Analysis of Moccasin limestone, Goodwin Ferry section.

(J. H. Gibboney, Analyst.)

	Per cent.
Insoluble	6.90
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	1.24
Lime (CaO)	50.10
Calcium carbonate ($CaCO_3$)	89.48
Magnesian (MgO)	0.75
Magnesium carbonate ($MgCO_3$)	1.57
Total	99.19

The lower, middle, and upper members of the Sevier shale corresponding to the Trenton, Utica, and Eden divisions of the general time scale have been described on a previous page. These are fairly well shown in this section where, aside from fossil evidence, these divisions can be recognized by difference in lithology. The Trenton portion as usual contains thin limestone layers, while the upper strata are highly arenaceous.

Analyses of Sevier shale, Goodwin Ferry section.

(J. H. Gibboney, Analyst.)

	I.	II.	III.
	Per cent.	Per cent.	Per cent.
Insoluble	5.12	41.48	71.88
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	2.92	6.04	8.56
Lime (CaO)	51.16	28.00	8.54
Calcium carbonate ($CaCO_3$)	91.39	50.00	15.25
Magnesia (MgO)	0.25	0.30	1.27
Magnesium carbonate ($MgCO_3$)	0.53	0.64	2.68
Total	99.96	98.16	98.37

I. Thin-bedded blue limestone, lower part (Trenton) Sevier shale.
II. Calcareous shale from lower portion of formation.
III. Sandy shale from Eden horizon, Sevier shale.

MONTGOMERY COUNTY.

The cement materials of Montgomery county are Ordovician limestones and shales, limited almost entirely to the western and northwestern slopes of Pearis mountain, where the only complete section of these rocks in the county is developed. A second area of Ordovician strata occurs just south of Ingles mountain, but here the strata are interbedded thin limestones and shales of the lower part of the Sevier shale, and are of little value. The area is several miles in length and less than one-half mile in width.

The Cambro-Ordovician dolomitic limestones are the surface rocks of a considerable portion of the county, but, as usual, a few of these layers are of suitable composition for lime or cement purposes.

Shales unassociated with the purer limestones are not uncommon. A band of Devonian shale averaging two miles in width occupies the northern part of the county. A second but much smaller area of the same shale lies south of Radford. In this general area the lower black shale of Devonian age is known as the Walker black shale, and the upper more sandy part as the Kimberling shale.

The south central part of the county is covered by a band of Cambrian red and green shale, described by Mr. M. R. Campbell as the Graysonton formation, but correlated with the Wautaga shale in the present report. These shales are interbedded with siliceous and occasionally purer blue limestones, but the whole formation is so charged with iron and other impurities that their only value in the present connection would be that

of mixing with purer limestones. Analyses of this same shale are given in the discussion of Roanoke and Wythe counties, where it also occurs.

Shales, conspicuous on account of their red to purplish color, outcrop along the edges of the coal-bearing sandstones of Price mountain. These shales are of Mississippian age and have been named from their occurrence at Pulaski, Va.

The various Ordovician strata noted in the following section may be observed at several localities in the county, but the rocks are generally so covered that no continuous detailed section could be found. This particular section has its beginning along the road about four miles east of Blacksburg, where the strata assigned to the Stones River formation are fairly well shown. Leaving the road and continuing eastward, across the farm of Mr. Giles Thomas, the lower shaly and upper more compact Athens strata are seen in the fields.

Geologic section through foothills and northwest slope of Pearis mountain, Montgomery county, Virginia.

	Feet.
Clinch sandstone:	
Massive white sandstone and quartzite forming crest of mountain	——
Bays sandstone:	
Red sandstone and sandy shales with occasional beds of conglomerate	——
Sevier shale:	
Olive, brown, and yellow shales, mainly covered	——
Athens shale:	
Dark to black shale passing upward into more compact black strata. Graptolites only fossils noted	600
Stones River formation:	
Coarsely crystalline blue and gray limestone with numerous trilobite remains, a species of *Agnostus* being highly characteristic	20
Dove and fine-grained dark blue limestone showing rather numerous gastropods on their weathered surface	100
Knox dolomite:	
Massive gray and steel blue magnesian limestone, weathering into chert	——

Samples of the Knox dolomite in Montgomery county have been selected for analysis by various writers. Professor Rogers publishes the results which are quoted below:

Analysis of rather coarse-grained limestone, two miles from Christiansburg, toward Blacksburg, Montgomery county, Virginia.

	Per cent.
Carbonate of lime	52.50
Carbonate of magnesia	34.34
Silica	6.84
Oxide of iron and alumina	0.84
Water and loss	3.48

Dr. Thomas L. Watson has published the following analyses[a] from samples collected by him in the vicinity of Blacksburg:

Analyses of Knox dolomite, vicinity of Blacksburg, Va.

	I.	II.	III.
	Per cent.	Per cent.	Per cent.
Calcium carbonate ($CaCO_3$)	66.43	87.35	46.46
Magnesium carbonate ($MgCO_3$)	24.21	7.34	37.38
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3) }	0.88	0.38	1.33
Insoluble residue	8.18	6.24	14.93

I. Limestone from the Bell quarry, 3 miles southwest of Blacksburg, Montgomery county, Va. J. R. Eoff, Jr., analyst.

II. Limestone from the Plunkett quarry, near the Bell quarry, 2½ miles southwest of Blacksburg, Montgomery county, Va. J. R. Eoff, Jr., analyst.

III. Limestone from the Davidson farm, 1 mile east of Blacksburg, Montgomery county, Va. J. R. Eoff, Jr., analyst.

PULASKI COUNTY.

Limestones and shales are abundant in Pulaski county, but neither material can be considered of much value as cement rock. The shales are of Devonian and Lower Cambrian age. The Devonian shales outcrop in a band crossing the county just north of Little Walker and Cloyds mountains; those of Lower Cambrian age are the red and purple Wautaga shale limited to the southern part of this area. Neither of these shale formations is associated with beds of purer limestone, and although their composition might be favorable for mixture, they can hardly be regarded as cement rock. No samples of either material were selected for analysis by the writer, but Dr. Watson[b] has published the following composition for the red shale:

Analysis of red shale, one-half mile southeast of Delton, Va.

(Thomas L. Watson, Analyst.)

	Per cent.
Silica (SiO_2)	69.29
Titanium oxide (TiO_2)	1.19
Alumina (Al_2O_3)	17.35
Iron oxide (Fe_2O_3)	4.78
Manganese oxide (MnO)	0.13
Magnesia (MgO)	0.92
Lime (CaO)	0.34

[a] Lead and Zinc Deposits of Virginia, Geol. Surv. of Virginia, Geological Series, Bull. No. 1, 1905, p. 74.

[b] Lead and Zinc Deposits of Virginia, Geol. Surv. of Virginia, Geological Series, Bull. 1, 1905, p. 76.

All of the central and eastern portions of Pulaski county are occupied by the Cambrian and Lower Ordovician dolomitic limestone. In this area these limestones are less massive and contain less chert than usual. Their composition, determined by field tests, was such that no samples were collected for detailed analysis.

BLAND COUNTY.

An abundance of Ordovician limestones and shales may be found in Bland county but without exception all the areas of outcrop are so hemmed in by the mountains and at such distances from transportation facilities that the rock cannot be considered of immediate value. The Ordovician limestones of the section exposed between the Walker mountain and Saltville faults cross Bland county in a northeast and southwest direction, outcropping just northwest of Walker mountain. The second area of outcrop is a strip following the foothills of the northwest side of Rich mountain. Just northwest of this strip the Knox dolomite is thrust over higher rocks, this fault being the northeast extension of the Copper creek fault.

The greater part of Bland county is included in the Pocahontas folio (No. 26) of the U. S. Geological Survey, and to this the reader is referred for more detailed descriptions and distribution of the geologic formations. No sample of the rock was analyzed, but the succession and character of the Ordovician rocks in Bland county are very similar to those of the same age in Scott and Russell counties.

WYTHE COUNTY.

In the northern part of Wythe county south of Little Walker mountain the Walker mountain fault brings the Ordovician (Sevier) shale in contact with the Carboniferous (Greenbrier) limestone, thus placing side by side the essential materials for cement manufacture. These Ordovician shales are exposed just northwest of Cove mountain, while the remainder of the Cove is occupied by the limestone. The essential points in the geology of this part of the county are mapped in the Pocahontas folio, U. S. Geological Survey, in which, however, only a very small portion of Wythe county is outlined. A short spur from the Norfolk and Western railroad would give the necessary transportation facilities, so that it would seem as if these limestones and shales might at some time be utilized.

The lower portion of these shales often run high in lime as the following analysis indicates, but higher in the series the lime constituent becomes very small:

Analysis of calcareous shales, Sevier shale, northern part of Wythe county, Virginia.

(J. H. Gibboney, Analyst.)

	Per cent.
Insoluble	29.70
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	3.18
Lime (CaO)	36.16
Calcium carbonate ($CaCO_3$)	64.57
Magnesia (MgO)	0.60
Magnesium carbonate ($MgCO_3$)	1.26
Total	98.71

The Greenbrier limestone, although considered separately in this report, is discussed here on account of its occurrence next to the Sevier shale. The formation is well exposed in the Cove and consists in general of heavily bedded blue limestone. Many of the layers run high in lime but others again are quite cherty. Toward the top of the formation the strata become less heavily bedded until calcareous shales are introduced. These pass into the red shale of the underlying Pulaski formation.

Analyses of Greenbrier limestone, northern part of Wythe county, Virginia.

(J. H. Gibboney, Analyst.)

	I.	II.	III.
	Per cent.	Per cent.	Per cent.
Insoluble	5.28	20.90	20.54
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	1.56	0.90	0.70
Lime (CaO)	51.02	42.70	42.94
Calcium carbonate ($CaCO_3$)	91.01	76.25	76.68
Magnesia (MgO)	0.60	0.70	0.36
Magnesium carbonate ($MgCO_3$)	1.26	1.48	0.76
Total	99.11	99.53	98.68

I. Rather pure blue limestone.
II and III. Blue cherty limestone.

The greater portion of Wythe county lies south of the Walker mountain fault, but is underlaid mainly by the dolomitic limestone and still older formations. In general the Valley portion of the southern two-thirds of

Wythe county exposes the Knox dolomite, but the mountains are mainly of Lower Cambrian quartzite. A small faulted patch of Ordovician strata occurs at the southern end of Draper mountain, but this can hardly be considered of much economic interest. The main Ordovician strata of the central portion of the county are located in small synclines exposing the Athens shale and Tellico sandstone as the youngest formations. Such a syncline makes up the Reservoir hill at Wytheville.

Wytheville section.—The Knox and associated formations in the immediate vicinity of Wytheville were fairly well shown at the time of the writer's visit. The following section along the south end of the Reservoir hill was taken in detail to show the character of the upper Knox or Beekmantown limestone more especially:

Geologic section, south side of Reservoir Hill, Wytheville, Va.

	Feet.
Athens shale (to top of hill):	
Dark brown to black shales weathering brownish gray. Graptolites in lower part only fossils noted	——
Knox (Beekmantown) dolomite:	
(i) Massive, dull brownish gray dolomite weathering into dirty white masses with their upper surfaces much cracked and fissured	5
(h) Dark dove, laminated, purer limestone. Opercula of *Maclurea* and *Ophileta complanata* noted on weathered surfaces	13
(g) Grayish blue, massive dolomite	3
(f) Dark dove, purer limestone with *Hormotoma artemesia* and other Beekmantown fossils	7
(e) Brown to gray dolomite similar to bed i	24
(d) Purer, laminated, dark limestone	3
(c) Massive dolomite with same characters as bed i	14
(b) Laminated, brownish gray limestone with *Ophileta complanata*	2
(a) Gray dolomite with thin sandy layers and a band of fossiliferous chert at the top and a similar cherty layer at the base	30

The Beekmantown portion of the above section is very characteristic for this part of Virginia. The lower and middle parts of the Beekmantown are of more shaly material—laminated limestone weathering into limey shales predominating, but the upper beds are as noted above—strata of massive, dull brownish-gray dolomite alternating with purer limestone. Weathering of these two limestones produces such different effects that the strata can be separated by this character alone, but the application of acid is a sure test. The purer limestone effervesces freely with acid, while the dolomites show little if any reaction.

Four analyses of the Beekmantown limestone of the above section were made, samples being selected to show the composition of the predominating kinds of rock.

Analyses of Beekmantown limestone, Wytheville, Va.

(Wm. M. Thornton, Jr., Analyst.)

	I.	II.	III.	IV.
	Per cent.	Per cent.	Per cent.	Per cent.
Silica (SiO_2)	10.12	0.89	4.99	1.68
Alumina (Al_2O_3), Iron oxide (Fe_2O_3)	1.75	0.80	2.16	0.53
Magnesia (MgO)	5.44	1.2	19.12	8.46
Lime (CaO)	42.14	53.72	30.01	45.12
Magnesium carbonate ($MgCO_3$)	11.39	2.53	40.21	17.79
Calcium carbonate ($CaCO_3$)	75.25	96.00	53.60	80.57
Total	98.51	100.22	100.96	100.57

I. Massive dolomite from bed *i* of section.
II. Dove-colored laminated limestone, bed *h*.
III. Brown to gray dolomitic limestone, bed *e*.
IV. Gray dolomitic limestone, bed *a*.

A sample of the Athens shale from the same section gave the following results:

Analysis of Athens shale, Reservoir Hill, Wytheville, Va.

(Wm. M. Thornton, Jr., Analyst.)

	Per cent.
Silica (SiO_2)	67.50
Alumina (Al_2O_3), Iron oxide (Fe_2O_3)	20.71
Magnesia (MgO)	0.63
Lime (CaO)	0.74
Water (H_2O) and organic matter	6.88
Total	96.46

Analyses of limestones.—The dolomitic limestones of Wythe county have received considerable attention from previous writers, due mainly to the associated lead and zinc deposits. Professor Rogers has given the following composition of a sample collected near the lead mines:

Analysis of light yellowish gray, compact limestone from near lead mines, Wythe county, Virginia.

	Per cent.
Calcium carbonate ($CaCO_3$)	16.29
Magnesium carbonate ($MgCO_3$)	13.29
Silica (SiO_2)	0.06
Alumina (Al_2O_3), Iron oxide (Fe_2O_3)	0.25
Water	0.05
Loss	0.06
Total	30.00

The following detailed analyses of samples collected by Dr. Thomas L. Watson from the same general region were made by Dr. W. E. Barlow, and published in the report by Watson on the "Lead and Zinc Deposits of Virginia."

Analyses of dolomitic limestones, Wythe county, Virginia.

	I.	II.	III.
Insoluble residue	Per cent.	Per cent.	Per cent.
Silica (SiO_2)	0.594	0.45	0.20
Titanium oxide (TiO_2)	0.073	Tr.	Tr.
Alumina (Al_2O_3)	none	none	none
Ferric oxide (Fe_2O_3)	0.334	0.24	0.37
Ferrous oxide (FeO)	0.19	0.17	0.22
Manganese oxide (MnO)	——	——	——
Lime (CaO)	0.193	0.37	Tr.
Magnesia (MgO)	29.085	29.50	30.71
Baryta (BaO)	20.54	19.93	21.56
Potash (K_2O)	none	Tr.	none
Soda (Na_2O)	0.22	0.56	0.12
Water (H_2O) 100° C—	0.38	1.03	0.10
Water (H_2O) 100° C+	2.58	3.73	3.92
Carbon dioxide (CO_2)	45.40	44.01	43.88
Phosphorous pentoxide (P_2O_5)	none	none	none
Sulphuric anhydride (SO_3)	none	none	none
Total	99.599	99.99	101.08

I. Limestone. Grayish white and moderately coarse crystalline. Specimens taken from the 190-foot level in the Austinville zinc and lead mines, Wythe county, Va. Dr. W. E. Barlow, analyst.

II. Limestone. White, coarsely crystalline, and crushed. Specimens taken from the 80-foot level at bottom of open cut, in the Austinville zinc and lead mines, Wythe county, Va. Dr. W. E. Barlow, analyst.

III. Limestone. White and medium crystalline. Specimens taken from the 80-foot level at bottom of open cut, in the Austinville zinc and lead mines, Wythe county, Va. Dr. W. E. Barlow, analyst.

The usual character of these limestones is dolomitic, as indicated in most of the foregoing analyses. Occasionally beds of purer limestones are interbedded with the prevailing dolomitic rock. Such a limestone from Bertha, Va., gave the following composition:[a]

Analysis of rather pure limestone, Bertha, Va.
(J. R. Eoff, Jr., Analyst.)

	Per cent.
Calcium carbonate ($CaCO_3$)	93.28
Magnesium carbonate ($MgCO_3$)	1.55
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3) }	0.36
Insoluble residue	2.06

[a]Lead and Zinc Deposits of Virginia, Geological Survey of Virginia, Geological series, Bulletin 1, 1905, p. 80.

Wautaga shale.—Underlying the dolomitic limestones are red, purple, and green shales correlated by Doctor Watson in his "Lead and Zinc Deposits of Virginia," with the Russell shales of more western localities. Although this eastern belt of shales is most probably of the same age as the Russell, the use of the name Wautaga, applied to similarly situated outcrops in more southern areas, has been extended to Virginia. In composition these shales are both siliceous and argillaceous. Thin limestone bands are sometimes interbedded, but these are too infrequent to be of value. The shale itself, as indicated in the following analysis by Doctor Watson, possesses a ratio between its silica and iron-alumina contents which would make the material of use for mixture with limestones in the cement manufacture. These shales are thinly laminated, and of a purplish-red, fine-textured, somewhat siliceous, and closely jointed. They are often found interbedded with shaly limestone.

Analysis of Wautaga shale, one-half mile south of Delton, Wythe county, Virginia.

(Thomas L. Watson, Analyst.)

	Per cent.
Silica (SiO_2)	62.29
Titanium oxide (TiO_2)	1.19
Alumina (Al_2O_3)	17.35
Iron oxide (Fe_2O_3)	4.73
Manganese oxide (MnO)	0.13
Magnesia (MgO)	0.92
Lime (CaO)	0.34

The Wautaga shale in Wythe county is limited to a rather narrow belt outcropping just north of Iron mountain. Going northeastward the band of outcrop becomes wider, until in Pulaski county a considerable area is occupied by the formation. Because of the crumpling and folding to which these strata have been subjected, the thickness has not been determined.

TAZEWELL COUNTY.

This county has the advantage over many of the counties in Virginia in having numerous outcrops of cement- and lime-making material in close proximity to a railroad. Between the stations of Cedar Bluff and Tiptop through the valley of Clinch river, the Norfolk and Western railroad passes over the purer Ordovician limestones for almost the entire distance. A second line of outcrop of the same rock is found southeast of Paint mountain, a third occurs about Morris Knob and extends northeastward, while a fourth may be found along the foothills of Clinch mountain. Of these the first is of most importance on account of transportation facilities and the analyses are mainly from samples collected along this strip.

General Geology.

Tazewell county is traversed along a northeast-southwest line, passing a little northeast of the center of the county, by a fault which is apparently a northeastward continuation of the Hunter Valley fault. This great thrust brings the Cambrian limestone in contact with the Devonian shales or still higher strata. Northwest of this fault the Appalachian coal field is encountered, while most of that portion of Tazewell county southeast of the break is occupied by rather gently folded Cambrian and Ordovician rocks. These folds bring the Ordovician limestone to the surface several times, as noted above.

The general geology of Tazewell county is well illustrated by structure sections presented in the Tazewell folio of the U. S. Geological Survey, while the detailed geology of the greater part of the county is shown on this and the adjoining Pocahontas folio.

In the various beds of outcrop in Tazewell county, a considerable variation in the members composing the important Ordovician limestones may be observed. The exact correlation of these strata as a whole cannot be made without a complete study of their faunas, and until this can be done it seems best to regard these rocks as a single formation, the Chickamauga limestone. For reasons discussed under the general stratigraphy of southwestern Virginia, the name Chickamauga limestone is not strictly applicable to these strata, but they have not been sufficiently studied to be certain of their exact age.

Stratigraphy.

The Ordovician rocks of Tazewell county, including the doubtful Clinch sandstones, are, in ascending order, as follows:

	Average thickness in feet.
6. Clinch sandstone	200
5. Bays sandstone	300
4. Sevier shale	1,200
3. Moccasin limestone	300
2. Chickamauga limestone	600
1. Knox dolomite	1,200±

The detailed stratigraphy of the band of Chickamauga limestone crossed or paralleled by the Norfolk and Western railroad has been given on page 174, in the general discussion of this formation. This same section, in

an abridged form, is given below under the discussion of sections and analyses. The strata quarried and well exposed at Five Oaks belong to this same belt of outcrop. All of the samples selected for analysis were from these two localities. The general succession and detailed character of the strata in the second and third lines of outcrop, namely southeast of Paint mountain and about Morris Knob, are given in the Thompson valley section on page 174. The fourth area, along the foothills of Clinch mountain, exhibits a section so similar to that at Thompson valley that no detailed record was made. Here, however, the basal beds of the Chickamauga limestone contain abundant fragments of Knox chert, varying up to 6 inches in diameter.

Sections and Analyses.

Five Oaks.—A good section of the Chickamauga limestone and associated formations is exposed along the Norfolk and Western railroad in the vicinity of this station. Here the typical Knox dolomite is followed by about 700 feet of Chickamauga limestone, in which the divisions indicated in the following section may be recognized. In general dove limestones predominate, and, as the analyses elsewhere show, run high in lime.

This particular section begins about one-quarter of a mile west of Five Oaks, continues east to the station, and then east to and beyond the quarry.

Geologic section, Five Oaks, Va.

	Feet.
Sevier shale:	
Olive, blue, and brown shales with thin bands at the base	——
Moccasin limestone:	
Red and reddish gray laminated clayey limestone with red, olive, and green shales at the top	200+
Chickamauga limestone:	
(k) Thin-bedded, earthy dove seams	10
(j) Heavy-bedded dove limestone full of fucoidal markings	42
(i) Laminar yellowish clayey limestone with a few dove and crystalline layers	55
(h) Bluish gray limestone, poorly exposed	75
(g) Dove limestone full of small specks and strings of calcite	75
(f) Massive, finely granular bluish gray limestone	35
(e) Fine-grained dove limestone with yellow seams	75
(d) Massive dove limestone, lower half full of dark specks, upper part laminar	100
(c) Fine-grained bluish limestone	60
(b) Cherty fine-grained to subgranular dark gray limestone	130
(a) Massive dove limestone with white crystalline specks	60
Knox chert and dolomite	——

The fine-grained blue limestone near the base of the Chickamauga gave the following analysis:

Analysis of fine-grained blue limestone, bed c of section, Five Oaks, Va.

(J. H. Gibboney, Analyst.)

	Per cent.
Insoluble	5.94
Alumina (Al_2O_3), Iron oxide (Fe_2O_3)	1.46
Lime (CaO)	51.34
Calcium carbonate ($CaCO_3$)	91.68
Magnesia (MgO)	0.33
Magnesium carbonate ($MgCO_3$)	0.70
Total	99.78

Massive dove and blue limestones make up the middle portion of the formation, but toward the top thin-bedded material is introduced. As a rule fossils are few in this division, but surfaces of the thin limestone slabs are sometimes covered with small ramose and bifoliate bryozoa. These less massive limestones, from tests in the field, seemed to contain less lime than the lower strata, but the following analysis of an average sample indicates practically the same proportion not only of the lime but of the insoluble content.

Analysis of thin-bedded, shaly limestone, bed i of section, Five Oaks, Va.

(J. H. Gibboney, Analyst.)

	Per cent.
Insoluble	6.04
Alumina (Al_2O_3), Iron oxide (Fe_2O_3)	1.14
Lime (CaO)	51.20
Calcium carbonate ($CaCO_3$)	91.42
Magnesia (MgO)	0.43
Magnesium carbonate ($MgCO_3$)	0.91
Total	99.51

The uppermost strata are mainly massive dove limestone which weather into flaggy layers. In contrast with the underlying Chickamauga strata, these dove-colored limestones contain an unusual amount of magnesian carbonate.

Analysis of dove limestone, bed j of section, Five Oaks, Va.

(J. H. Gibboney, Analyst.)

	Per cent.
Insoluble	4.56
Alumina (Al_2O_3), Iron oxide (Fe_2O_3)	1.84
Lime (CaO)	49.14
Calcium carbonate ($CaCO_3$)	87.75
Magnesia (MgO)	2.09
Magnesium carbonate ($MgCO_3$)	4.40
Total	98.55

About 300 feet of red- and drab-colored clayey limestones follow the thin-bedded dove layers terminating the preceding formation. These have the general character and hold the stratigraphic position of the Clinch mountain Moccasin limestone. Fossils are exceedingly rare, so that in this particular area the paleontologic evidence is of little value in correlation. With the exception of color the impure limestones of this Moccasin formation physically are much alike. A considerable difference, however, is shown in their chemical composition according to the following analyses:

Analyses of Moccasin limestone, vicinity of Five Oaks, Va.

(J. H. Gibboney, Analyst.)

	I.	II.
	Per cent.	Per cent.
Insoluble	24.72	13.20
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3) }	3.94	2.66
Lime (CaO)	38.48	45.40
Calcium carbonate ($CaCO_3$)	68.71	81.07
Magnesia (MgO)	0.64	0.87
Magnesium carbonate ($MgCO_3$)	1.35	1.83
Total	98.72	98.76

I. Impure, red limestone.
II. Dove-colored, argillaceous limestone.

The various divisions of the Sevier shale which follow the Moccasin limestone may be seen more or less well developed in the vicinity of Five Oaks. This applies especially well to the lower or more important portion economically considered. The Sevier changes from thin-bedded limestones and calcareous shales in the lower part through various gradations of shaly material to sandy shales in the topmost portion, with a total thickness of about 1,200 feet. Some of the lower shales, especially when unweathered, have more of the appearance of argillaceous limestone, and, as their composition shows, ought to be a good cement rock. Good raw material for the same purpose could also be had from a mixture of the calcareous shales and interbedded limestones if the analyses quoted hold for the rock in general. The increased amount of silica in these upper shales is shown in analysis IV of the table:

Analyses of Sevier shales, Five Oaks, Va.

(J. H. Gibboney, Analyst.)

	I.	II.	III.	IV.
	Per cent.	Per cent.	Per cent.	Per cent.
Insoluble	22.50	8.14	28.62	73.00
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3) }	2.34	1.24	3.76	11.28
Lime (CaO)	41.34	50.54	36.42	6.76
Calcium carbonate ($CaCO_3$)	73.82	90.25	65.03	12.07
Magnesia (MgO)	0.05	0.28	0.99	0.04
Magnesium carbonate ($MgCO_3$)	0.11	0.58	2.08	0.09
Total	98.77	100.21	99.47	96.44

I. Compact argillaceous layers in lower part of the formation.
II. Limestone bands from same division.
III. Calcareous shales at base of Sevier shales.
IV. Sandy shales of upper part of formation.

Tazewell.—The purer limestones are abundant and well shown at Tazewell, the town itself being located upon the Chickamauga formation. A second line of outcrop, traversed by the railroad, occurs about a mile north, and it is this latter band which furnished the following section:

Section of Chickamauga limestone, vicinity of Tazewell, Va.

	Feet.
Chickamauga limestone:	
(h) Blue gray to red laminar clayey limestone	30
(g) Massive subcrystalline gray crinoidal limestone	18.5
(f) Massive and thin-bedded dove limestone	220
(e) Rather pure dove limestone	200
(d) Dark gray siliceous limestone	100
(c) Massive dove limestone	40
(b) Massive gray limestone with small chert nodules	40
(a) Thin-bedded argillaceous limestone	70
Knox dolomite	——

Knox dolomite.—This great limestone formation makes up the first ridge north of the railroad in this section, and here, as usual, consists of gray cherty dolomite rock unsuitable for the manufacture of cement. The total thickness of the Knox in this area is not less than 2,400 feet, and the upper half, or Ordovician member, is at least 1,200 feet thick. Over much of Tazewell county a thin bed of red shaly limestone or limestone with chert

pebbles is found at the close of the Knox, marking the unconformity between this and the succeeding Chickamauga limestone; but along the southern slope of the ridge just mentioned the upper part of this dolomite carries the barite deposits described by Dr. Thomas L. Watson in the "Mineral Resources of Virginia." The descriptions and analyses of the Chickamauga, Moccasin, and Sevier formations following have particular reference to the second band of Ordovician strata, namely the one passing through the town of Tazewell.

Chickamauga limestone.—The gray dolomitic Knox limestone is followed in this vicinity by argillaceous and thin siliceous strata having an unfavorable composition. Some of these strata are quite pure, but a few yield chert upon weathering. This chert, which differs from that of the Knox dolomite in being more cellular and of a dark or dirty red color, becomes more abundant in the weathered débris of the succeeding beds, which, however, when quarried, show a small percentage of silica.

Analyses of massive limestone, near base of Chickamauga limestone, bed b, Tazewell, Va.

(J. H. Gibboney, Analyst.)

	I.	II.
	Per cent.	Per cent.
Insoluble	2.04	1.80
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3) }	0.50	1.00
Lime (CaO)	53.80	53.24
Calcium carbonate ($CaCO_3$)	96.07	95.42
Magnesia (MgO)	1.33	0.43
Magnesium carbonate ($MgCO_3$)	2.78	0.91
Total	99.79	99.13

I. Massive, finely crystalline limestone.
II. Blue, coarsely crystalline limestone.

The remaining strata of the Chickamauga limestone, some 500 feet in thickness, consist here essentially of dove limestones, most of which are massive. Thin-bedded limestones with a small amount of interbedded yellow shales occur in the upper part, but even these appear massive. The following analyses show slight differences in composition of these dove limestones:

Analyses of dove limestone, Chickamauga limestone, Tazewell, Va.

(J. H. Gibboney, Analyst.)

	I.	II.
	Per cent.	Per cent.
Insoluble	5.36	2.82
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	0.72	0.78
Lime (CaO)	51.32	53.90
Calcium carbonate ($CaCO_3$)	91.64	96.25
Magnesia (MgO)	0.67	0.51
Magnesium carbonate ($MgCO_3$)	1.40	1.06
Total	99.12	100.91

I. Thin-bedded dove limestone from middle portion of series, bed *e*.
II. More massive dove limestone from near top of series, bed *f*.

Moccasin limestone.—The 300 feet of practically unfossiliferous, impure, shaly limestone following the Clinch have been mapped in the Tazewell area under this name. These strata as elsewhere are usually red in color, although drab layers are encountered. In most of the samples taken for analysis the drab layers run higher in lime than the red, and the following is not an exception to this rule. In the vicinity of Tazewell these strata are best seen along the road to Liberty Hill, where for several miles the red rock tilted at a high angle is quite conspicuous.

Analysis of impure limestone, Moccasin formation, Tazewell county, Virginia.

(J. H. Gibboney, Analyst.)

	Per cent.
Insoluble	8.28
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	1.72
Lime (CaO)	49.36
Calcium carbonate ($CaCO_3$)	88.23
Magnesia (MgO)	0.96
Magnesium carbonate ($MgCO_3$)	2.02
Total	100.25

Sevier shale.—Comparing the various analyses of the Chickamauga limestone it will be seen that the amount of iron, alumina, and silica is too small for a cement material, and that therefore calcareous shales for mixture are necessary. Shales of this nature can be had in abundance in the lower or Trenton horizon of the Sevier shale, found in abundance both north and south of Tazewell.

In the lower portion of these shales in the Tazewell area the limestone bands are so numerous that this part may almost be called a limestone formation. The interbedded shales also are highly calcareous, so that these rocks ought to prove an important source of supply for cement rock.

Analyses of Sevier shales, Tazewell, Va.

(J. H. Gibboney, Analyst.)

	I.	II.
	Per cent.	Per cent.
Insoluble	11.68	20.48
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3) }	1.52	2.04
Lime (CaO)	48.08	42.76
Calcium carbonate ($CaCO_3$)	85.86	76.36
Magnesia (MgO)	0.45	0.51
Magnesium carbonate ($MgCO_3$)	0.94	1.06
Total	100.00	99.94

I. Compact, black limestone, lower part of Sevier shale.
II. Calcareous shales, lower part of Sevier shale.

These lower calcareous portions of the Sevier shale do not exceed 300 feet in thickness. The remaining 900 or more feet contain but little lime and therefore need not be discussed as a cement rock.

The succeeding Bays and Clinch sandstones, as noted elsewhere, are of no importance in cement manufacture.

SMYTH COUNTY.

The Walker mountain fault passes through Smyth county along a southwest-northeast line, dividing it into southeastern and northwestern portions of nearly equal dimensions. This fault traverses the western part of the Valley of Virginia and brings the Knox dolomite or older limestones in contact with the Mississippian gypsiferous shales. East of this fault line the strata are limestones or shales generally unsuited for cement material. The important cement rocks are Ordovician limestones and shales outcropping along a northeast-southwest strip following the western foothills of Walker mountain. With the exception of the vicinity of Saltville, this strip is everywhere at such a distance from railroads that the material cannot at present be considered of much value other than for local use. In the Valley west of Walker mountain the Knox dolomite and underlying

Cambrian limestone are exposed, but proceeding westward these strata are found to be again faulted against the Mississippian shales as to the east of the mountain. This second fault is well shown at Saltville and has received its name from that town. The Cambro-Ordovician section exposed between these two faults is essentially the same throughout the county and therefore only a single new section with analyses of the rocks is given. The general arrangement of the strata across the major portion of the county is illustrated by the structure section on page 242.

The section across Walker mountain north of Marion has been given in the discussion of the general geology of southwestern Virginia. This, in an abridged form, is repeated below:

Walker mountain section.—The section given under this name is exposed along the northwestern side of Walker mountain, starting with the Clinch sandstone at the crest of the mountain and ending in Rich valley to the west.

Walker mountain section, north of Marion, Va.

	Feet.
Clinch sandstone:	
Massive white quartzite and sandstone forming crest and southern slope of mountain	100±
Bays sandstone:	
Red to brown sandstone, sandy shale and conglomerate	300
Sevier shale:	
Brown to olive and gray shales, calcareous in basal part, argillaceous above and arenaceous in upper third	1,500
Moccasin limestone:	
Impure and argillaceous red limestone	300
Holston marble and associated strata:	
(e) Unfossiliferous drab shales	40
(d) Nodular limestone and yellowish to gray shales holding many bryozoa	30
(c) Massive gray and pink marble	30
(b) Clayey nodular limestone and shale	50
(a) Massive crystalline limestone	40
Athens shale:	
Dark to black shale with black slaty limestone at the base	500±
Stones River formation:	
(c) Coarsely crystalline gray to blue limestone weathering into layers 1 to 4 inches in thickness. Upper beds pinkish and of a marble-like structure	100
(b) Mottled dark gray massive magnesian limestone	40
(a) Massive dove limestone speckled with calcite spots	30
Knox dolomite:	
Massive grayish dolomite with little chert	——

The Stones River, Athens and Holston divisions furnish the best cement materials in this section, and samples selected for analysis were limited to these rocks.

The massive dove limestones (bed a) of the Stones River formation showed, as usual, a high lime content, while the coarsely crystalline beds in the upper part (bed c) gave an almost equal amount of lime carbonate. The use of these limestones for mixing with the associated Athens shale is obvious.

Analyses of limestones of Stones River formation.

(Wm. M. Thornton, Jr., Analyst.)

	I.	II.	III.
	Per cent.	Per cent.	Per cent.
Insoluble residue	1.35	1.52	1.31
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	1.02	1.24	1.43
Calcium carbonate ($CaCO_3$)	94.05	92.70	92.67
Magnesium carbonate ($MgCO_3$)	2.05	4.10	3.33
Total	98.47	99.56	98.74

I and II. Dove limestone, bed *a*, Walker mountain section.
III. Coarsely crystalline gray limestone, bed *c*, of same section.

The strata following the Stones River limestone and identified with the Athens shale of more eastern portions of the Great Valley form an ideal cement rock, if the following analysis can be regarded as characteristic. It is definitely known that higher in this shale formation, the amount of lime carbonate in the rock becomes much less. The associated purer limestone would then be of use in making the proper mixture.

Analysis of black, slaty limestone, Athens formation, Walker mountain section.

(Wm. M. Thornton, Jr., Analyst.)

	Per cent.
Insoluble residue	16.62
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	4.75
Calcium carbonate ($CaCO_3$)	74.82
Magnesium carbonate ($MgCO_3$)	2.52
Total	98.71

The Holston marble in this section, as elsewhere, is associated with shales and thin limestones, containing the same fauna. The limestones are probably of more importance than the shaly materials, and samples were selected accordingly.

Analyses of limestones (Holston marbles), Walker mountain section.

(Wm. M. Thornton, Jr., Analyst.)

	I.	II.
	Per cent.	Per cent.
Insoluble residue	1.13	3.68
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3) }	1.01	1.20
Calcium carbonate ($CaCO_3$)	86.66	93.03
Magnesium carbonate ($MgCO_3$)	0.69	2.10
Total	89.49	100.01

I. Coarsely crystalline, pink marble from bed *c*.
II. Massive crystalline limestone from bed *a*.

Lyon Gap section.—The following section is exposed along the road through Lyon Gap, northeast of Glade Spring, Va., starting at the cross roads near McHenry creek, west of the Gap. The section concludes with the Clinch sandstone at the top of Walker mountain.

Geologic section, Lyon Gap, Va.

		Feet.
11.	Clinch sandstone, white quartzite and sandstone	——
10.	Bays sandstone. Yellow and red sandy shales and sandstones with arenaceous limestone in lower portion	300
9.	Sevier (upper) shale. Yellow shales with thin arenaceous limestone layers	1,000
8.	Sevier shale. Brown to yellow shales	600
7.	Moccasin limestone. Purplish shales and impure reddish limestone	400
6.	Holston limestone. Blue and gray argillaceous limestone	500
5.	Holston limestone. Thin-bedded argillaceous and crystalline limestone	100
4.	Athens shale. Dark blue calcareous shales	400
3.	Stones River limestone. Compact dark argillaceous and magnesian limestone	200
2.	Knox dolomite. Compact gray clayey limestone weathering into shales	30+
1.	Knox dolomite. Dolomitic limestone weathering into chert	——

The most important beds in this section economically considered are numbers 3 to 6, and with the exception of two analyses of the Knox dolomite the samples for analysis were restricted to this part of the section.

Bed 1.—The major portion of the Valley west of Walker mountain is occupied by the Knox dolomite which, upon weathering, leaves the char-

acteristic red soil and residual chert. A sample of the unweathered magnesian rock from the upper part of the formation gave the following results on analysis:

Analysis of Knox dolomite, Lyon Gap section.

(J. H. Gibboney, Analyst.)

	Per cent.
Insoluble	1.40
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	0.08
Lime (CaO)	31.48
Calcium carbonate ($CaCO_3$)	56.22
Magnesia (MgO)	20.29
Magnesium carbonate ($MgCO_3$)	42.61
Total	100.31

Bed 2.—A compact, light-colored, clay-like rock which frequently forms the topmost member of the Knox in southwestern Virginia, is present in the Lyon Gap section to the extent of a thickness of at least 30 feet. Although this particular rock greatly resembles an argillaceous limestone and would seem from a superficial examination only to run low in silica, its analysis shows an unusually large amount of insoluble matter. This, however, was not entirely unexpected as the analysis of the corresponding bed in the Clinchport (Scott county) section also shows a considerable amount of silica. According to these analyses neither beds 1 nor 2 are of value as a Portland cement material.

Analysis of Knox dolomite, bed 2, Lyon Gap section.

(J. H. Gibboney, Analyst.)

	Per cent.
Insoluble	40.44
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	4.00
Lime (CaO)	16.90
Calcium carbonate ($CaCO_3$)	30.18
Magnesia (MgO)	11.42
Magnesium carbonate ($MgCO_3$)	23.98
Total	98.61

Bed 3.—This and the following beds are the most important in the Lyon Gap section from a cement-making standpoint. Bed 3 is composed mainly of dark, compact, argillaceous limestone, but interpolated with this are layers of bluish black crystalline limestone. The rock has every appearance of a good cement material, but the particular stratum from which the sample for analysis was taken seems to run higher in magnesium

carbonate than the beds in general would indicate. However, mixture with the purer limestone layers occurring in the same division, or with the calcareous shales of the overlying bed, would remedy this defect.

Analysis of argillaceous limestone, Lyon Gap section.

(J. H. Gibboney, Analyst.)

	Per cent.
Insoluble	16.12
Alumina (Al_2O_3), Iron oxide (Fe_2O_3)	3.20
Lime (CaO)	42.74
Calcium carbonate ($CaCO_3$)	76.32
Magnesia (MgO)	1.34
Magnesium carbonate ($MgCO_3$)	2.82
Total	98.46

Bed 4.—Calcareous shales succeed the argillaceous limestones of bed 3 and reach a thickness of at least 400 feet. These vary in color from black to dark blue, the latter, however, predominating. Toward the top of the bed the strata lose their shaly character and become more of the nature of argillaceous limestone. The dark-colored shales of this bed contain less lime than the dark blue portion, as the following analyses indicate:

Analyses of shales, bed 4, Lyon Gap section.

(J. H. Gibboney, Analyst.)

	I.	II.
	Per cent.	Per cent.
Insoluble	25.80	17.58
Alumina (Al_2O_3), Iron oxide (Fe_2O_3)	3.74	2.44
Lime (CaO)	37.96	43.44
Calcium carbonate ($CaCO_3$)	67.36	77.59
Magnesia (MgO)	0.12	0.04
Magnesium carbonate ($MgCO_3$)	0.24	0.08
Total	97.14	97.69

I. Dark shales.
II. Dark blue calcareous shales.

Bed 5.—The somewhat argillaceous limestone occurring at the top of bed 4 passes gradually into typical thin-bedded clayey limestone with occasional bands of more crystalline material. These crystalline strata run high in lime, but the argillaceous rocks with the exception of color are very similar to the gray argillaceous limestone of the succeeding bed.

Analysis of shales, bed 5, Lyon Gap section.

(J. H. Gibboney, Analyst.)

	Per cent.
Insoluble	4.66
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	1.46
Lime (CaO)	51.50
Calcium carbonate ($CaCO_3$)	91.96
Magnesia (MgO)	0.51
Magnesium carbonate ($MgCO_3$)	1.06
Total	99.14

Bed 6.—This division of the section composes another important series of strata with reference to a source of cement rock. It comprises about 500 feet of blue and gray argillaceous limestones occurring in thin courses. A few thin shaly layers are sometimes interplaced, but usually the limestone is compact upon unweathered surfaces. In weathering the layers split up into thin courses characteristic of such limestones and these often break up into small fragments or blocks. Although the blue and gray limestones of this bed vary somewhat in their analyses, the general percentage composition of each is essentially the same.

Analyses of argillaceous limestones, bed 6, Lyon Gap section.

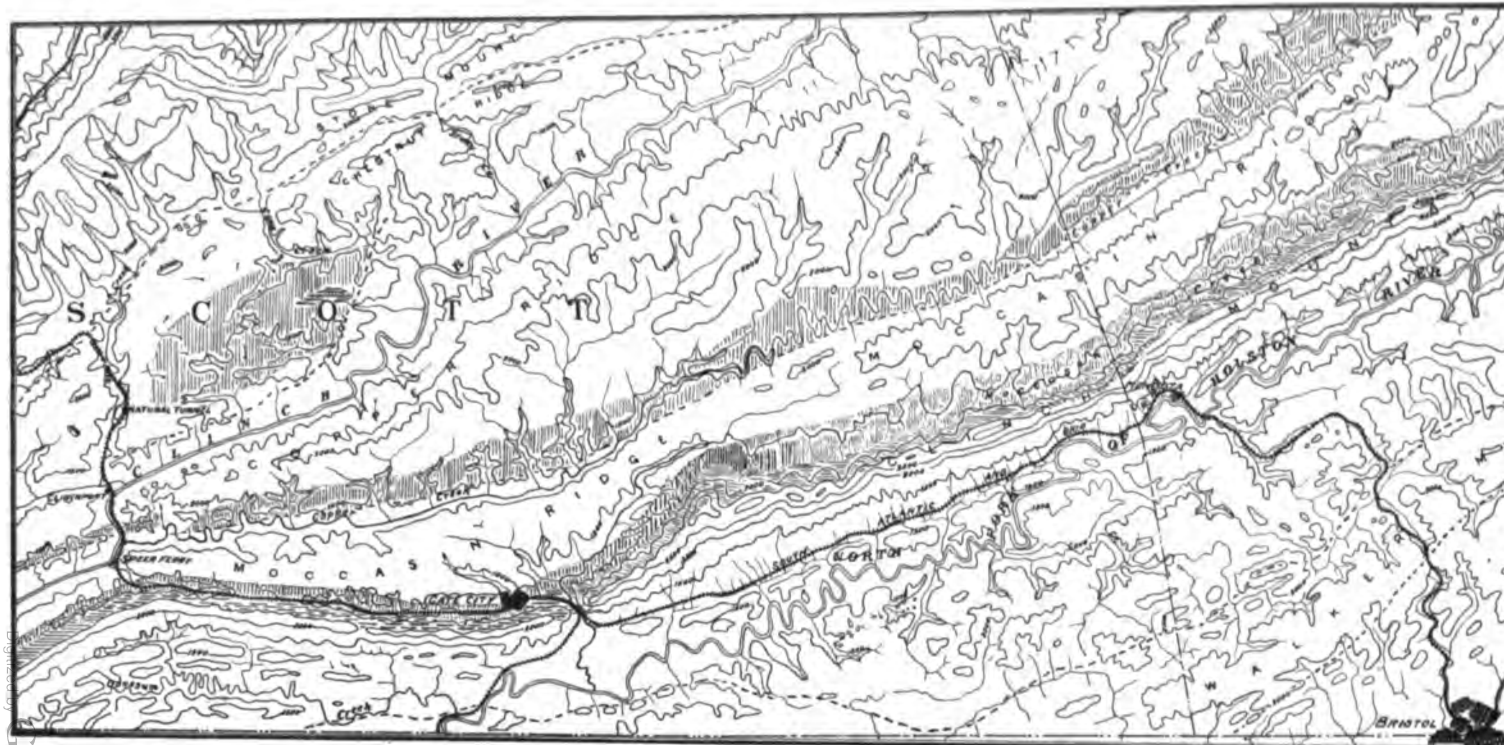
(J. H. Gibboney, Analyst.)

	I.	II.
	Per cent.	Per cent.
Insoluble	12.18	14.96
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	0.98	1.70
Lime (CaO)	47.56	45.06
Calcium carbonate ($CaCO_3$)	84.93	80.50
Magnesia (MgO)	0.75	0.38
Magnesium carbonate ($MgCO_3$)	1.58	0.81
Total	99.67	97.97

I. Blue argillaceous limestone.
II. Gray argillaceous limestone.

SCOTT AND RUSSELL COUNTIES.

Geologically these two counties are so similar that in order to save repetition they are treated together. Both are bounded on the east and southeast by Clinch mountain, while Powell mountain and Dividing ridge delimit each on the west and northwest. Clinch river drains their central portion, while Copper ridge and Moccasin ridge are important elevations between Clinch river and Clinch mountain.



Ordovician limestones. Ordovician shales.

Fig. 24.—Map showing distribution of cement materials of southwestern Virginia,

On account of faulting, two strips of Ordovician strata traverse both counties. The first line of outcrops is along the western slope of Clinch mountain and the second occurs similarly, just west of Moccasin ridge. The eastern line of outcrops forms a portion of the section bounded on the east by the Saltville fault traversing the western part of Washington county. The section commences on the east with Carboniferous rocks and continues westward, exposing the various formations in descending order until in the vicinity of Copper creek the Cambrian limestones are found thrust upon Ordovician rocks. This second fault—the Copper creek fault—follows the creek of the same name in a general way, and, as a rule, throughout both of the counties under discussion, the Cambrian rocks underlying the Knox dolomite are found thrust upon either the Moccasin or Holston limestones. A third great break, the Hunter valley fault, passes through the western part of the two counties. In the great thrust which has occurred here, all of the Ordovician rocks have been cut out, the Cambrian limestone being found next to Devonian or Carboniferous strata. The detailed geology of the greater part of Scott and Russell counties is given in the Estillville and Bristol folios of the U. S. Geological Survey.

Clinchport Section.

The geologic structure and character of the limestone of economic importance in these counties are well shown along the Virginia and Southwestern railroad between Clinchport and Gate City. As this railroad cuts across both of the strips of Ordovician strata mentioned above, the section along this line has been studied in detail. Starting with the lowest formation, geologically speaking, the Russell shales, exposed just north of Clinchport, the succeeding Cambrian and Ordovician strata are seen until proceeding south the Copper creek fault is encountered, when the Holston limestone is found overthrust by the Russell shales. The section then continues southward without interruption to Clinch mountain, capped by the Clinch sandstone. As this section illustrates the general structure and sequence of rocks in both Scott and Russell counties, samples for analysis were taken from most of the formations.

Geologic section exposed along railroad, Clinchport, Va., south to crest of Clinch mountain.

(Thickness approximate.)	Feet.
1. Russell shale (exposed just north of Clinchport). Sandy shales and sandstones with brown shales at the top	1,000
2. Rutledge limestone (exposed at Clinchport). Dark, impure magnesian limestone	200
3. Rogersville shale. Blue to brown calcareous shale	100

4.	Maryville limestone. Massive and blue mottled limestone	600
5.	Nolichucky shale. Brown to yellow and green calcareous or arenaceous shale	500
6.	Knox dolomite. Gray magnesian limestone, sandy in middle part and cherty toward the top of the same; grayish non-cherty dolomite in the upper part	2,100
7.	Holston limestone. Heavily bedded crystalline and argillaceous dark blue limestone.	
	Fault. Beds 8 to 13 have essentially the same lithology and thickness as beds 1 to 6, respectively.	
8.	Russell shale.	
9.	Rutledge limestone.	
10.	Rogersville shale.	
11.	Maryville limestone.	
12.	Nolichucky shale.	
13.	Knox dolomite.	
14.	Holston limestone and associated shales. Thin-bedded blue limestone and yellow shales with lenses of red to gray marble toward the base	900
15.	Moccasin limestone. Red argillaceous limestone	500
16.	Sevier shale. Yellow and blue calcareous shales	1,500
17.	Bays sandstone	300
18.	Clinch sandstone	300

The graphic representation of this succession of strata is represented in the structure section on page 242, figure 25.

Description of Formations and Analyses.

Russell shale.—This formation is usually found along the great fault line in these two counties so that the base is not seen. The thickness observed, however, is about 1,000 feet of shales and sandstones with few very impure limestones. The lower portion of the formation is sandy, but toward the top brown argillaceous shales are developed. Analyses of these sandy and argillaceous shales are given below:

Analyses of Russell formation, vicinity of Clinchport, Va.

(J. H. Gibboney, Analyst.)

	I.	II.
	Per cent.	Per cent.
Insoluble	41.72	89.52
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	5.68	7.22
Lime (CaO)	17.32	0.40
Calcium carbonate ($CaCO_3$)	30.93	0.72
Magnesia (MgO)	9.17	1.05
Magnesium carbonate ($MgCO_3$)	19.29	2.21
Total	97.62	99.67

I. Brown argillaceous shales, upper part of formation.
II. Sandy shales several hundred feet from top of formation.

Rutledge limestone.—The brown argillaceous shales of the preceding formation are followed by 200 feet of limestone, which is unusual in composition on account of the small amount of iron, alumina, and insoluble material, and the relatively larger amount of magnesia. Near Clinchport this limestone consists mostly of dark magnesian beds together with thin streaks of gray-colored rock alternating with impure black layers. The amount of magnesia is high in both the gray and dark rock but less in the former.

Analyses of Rutledge limestone, vicinity of Clinchport, Va.
(J. H. Gibboney, Analyst.)

	I.	II.
	Per cent.	Per cent.
Insoluble	3.88	2.58
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	1.36	1.12
Lime (CaO)	46.22	30.80
Calcium carbonate ($CaCO_3$)	82.53	55.00
Magnesia (MgO)	5.62	19.70
Magnesium carbonate ($MgCO_3$)	11.80	41.37
Total	99.57	100.07

I. Gray limestone, near base of formation.
II. Dark limestone, near top of formation.

Rogersville shale.—Field tests of this shale seemed to indicate that it contained enough lime to be worthy of consideration as a cement rock. The analyses given below are of samples selected to show extremes in composition, and according to them the amount of calcium carbonate varies considerably. In all probability an average of these analyses cannot be considered as representing that of the typical shale, since this undoubtedly carries more lime than indicated by these figures.

Analyses of Rogersville shale, vicinity of Clinchport, Va.
(J. H. Gibboney, Analyst.)

	I.	II.
	Per cent.	Per cent.
Insoluble	31.22	87.48
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	6.20	1.32
Lime (CaO)	21.41	3.60
Calcium carbonate ($CaCO_3$)	38.23	6.42
Magnesia (MgO)	10.90	1.76
Magnesium carbonate ($MgCO_3$)	22.89	3.70
Total	98.54	98.92

I. Calcareous shales, upper part of formation.
II. Sandy shales, lower part of formation.

Maryville limestone.—The preceding shale formation and the following Nolichucky shale are separated in these two counties by about 500 feet of heavily bedded blue limestone. These strata as a rule are rather high in lime and therefore form one of the cement rock resources of this part of the state. Some of the layers hold a considerable amount of chert while others carry too much magnesia for a cement rock. Therefore in the possible use of this rock a selection of the high lime strata would be necessary. A detailed section of the Maryville limestone band exposed near Clinchport has been given on page 150.

Analyses of Maryville limestone, vicinity of Clinchport, Va.
(J. H. Gibboney, Analyst.)

	I.	II.	III.	IV.
	Per cent.	Per cent.	Per cent.	Per cent.
Insoluble	35.06	31.78	10.54	2.16
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3) }	1.90	1.84	0.64	0.54
Lime (CaO)	29.16	35.78	46.72	50.80
Calcium carbonate ($CaCO_3$)	52.07	63.89	83.43	89.43
Magnesia (MgO)	5.33	0.93	1.82	3.79
Magnesium carbonate ($MgCO_3$)	11.20	1.96	3.82	7.95
Total	100.23	99.47	98.43	100.08

I and II. Cherty, black limestone.
III. Blue crystalline limestone.
IV. Grayish, subcrystalline limestone.

Nolichucky shale.—The most calcareous formation of Cambrian shales follows the Maryville limestone and reaches a thickness of 700 feet. The outcrops of this shale are usually along the northern edge of the areas of Knox dolomite. Since the shale is more easily eroded than the dolomite it generally forms the northern slope of the cherty Knox ridges. The composition of most of the Nolichucky shale is such that with the addition of pure limestone it can be considered a cement rock. A rather pure blue limestone with a thickness of several hundred feet sometimes occurs as a lens in this shale. The following analysis is of a carefully selected average sample of this shale:

Analysis of Nolichucky shale, vicinity of Clinchport, Va.
(J. H. Gibboney, Analyst.)

	Per cent.
Insoluble	38.68
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3) }	5.28
Lime (CaO)	29.46
Calcium carbonate ($CaCO_3$)	52.61
Magnesia (MgO)	0.80
Magnesium carbonate ($MgCO_3$)	1.69
Total	98.26

Knox dolomite.—The description of this great limestone formation, given on pages 151 to 157, applies to Russell and Scott counties as well as other parts of southwestern Virginia, so that these strata need not be dwelt upon at this point. The particular area of Knox dolomite under discussion is of interest in that this section exposes the complete thickness of which almost every foot can be seen. This particular section is south of Clinchport, where Clinch river cuts into Copper ridge. The analyses given below are believed to represent the various divisions of the Knox fairly well. The lowest beds are purer limestone than the higher strata, but an occasional layer in the upper part gives a high percentage of lime and a relatively small amount of magnesia. A rather conspicuous white argillaceous limestone has been noted at the top of the Knox in this area and is in marked contrast to the overlying Holston marbles. Analyses of this bed are given under the Speer Ferry section.

Analyses of Knox dolomite, vicinity of Clinchport, Va.

(J. H. Gibboney, Analyst.)

	I.	II.	III.
	Per cent.	Per cent.	Per cent.
Insoluble	9.60	7.56	8.09
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3) }	0.40	0.98	1.52
Lime (CaO)	50.60	30.10	46.64
Calcium carbonate ($CaCO_3$)	90.35	58.75	83.28
Magnesia (MgO)	4.29	18.00	3.18
Magnesium carbonate ($MgCO_3$)	9.00	37.80	6.68
Total	110.35	105.09	99.57

I. Bluish gray limestone, lower part of Knox.
II. Gray dolomitic limestone, upper part of Knox.
III. Purer limestone layer in upper Knox.

Holston marble.—Heavily bedded dark blue limestones referred to the Holston follow the Knox in regular order about two miles south of Clinchport, but only a portion of their entire thickness is shown since a short distance further south the Copper creek fault brings the Russell shale into contact with them. Then, proceeding southward from this fault line, the same succession of beds with essentially the same lithology is exposed until, in the vicinity of Speer Ferry, the Knox dolomite and Holston formation are again encountered. This latter band of purer limestone is traversed by the Virginia and Southwestern railroad from Speer Ferry to Gate City, and for that reason, as well as its better development, samples for analysis

were collected from this more southern area, which is described under the Speer Ferry section.

The Holston in the Clinchport region is made up of the usual marbles, associated with shales, and massive to thin-bedded limestones, reaching a total thickness of about 800 feet. In the section along the railroad, less than half of this thickness is exposed on account of the faulting noted above, but further east, along the same line of outcrop, the fault is between the Russell and Moccasin formations, thus giving the complete Holston section. The Holston strata seen along the railroad south of Clinchport, are as follows:

Section of Holston marble and underlying limestone, 1.5 miles south of Clinchport, Va.

	Feet.
Russell shale.	
Fault.	
Holston formation:	
Red marble	——
Nodular and shaly limestone	50
Massive compact to slightly granular dark limestone	85
Dark blue finely granular fossiliferous limestone	145
Dark, rather thin-bedded, argillaceous limestone with numerous bands containing small nodules of dark chert	100
Knox dolomite	——

Essentially the same succession of strata preceding the marbles occurs in the typical Holston band along the foothills of Clinch mountain. This section is given under the discussion of the Speer Ferry region.

Speer Ferry Section.

The various divisions of the Holston are well exhibited in the railroad cuts along the new tunnel through Clinch mountain and in natural exposures about Speer Ferry. Commencing with the band of Knox dolomite outcropping just north of this place, the following complete section is well presented, going south to the top of Clinch mountain:

Geologic section, Speer Ferry, Va.

	Feet.
6. Clinch sandstone. Coarse, white, massive quartzite and sandstone outcropping at crest of Clinch mountain	——
5. Bays sandstone. Red, sandy shales and sandstone containing numerous Lorraine fossils	300
4. Sevier shale. Yellow or blue shales, calcareous in lower part especially	1,500

3.	Moccasin limestone. Red argillaceous limestone with a few drab-colored layers	400
2.	Holston marble and associated strata. Cherty limestone, marble, purer limestones and shales in the following order:	
	(l) Yellow to bluish gray shales and laminated earthy and shaly limestone	250
	(k) Blue to gray coarsely crystalline limestone weathering into thin, somewhat nodular layers	80
	(j) Shales and thin irregular platy limestone interbedded. Fossils most numerous in this division, *Receptaculites biconstrictus* and *Echinosphærites* being characteristic forms	200
	(i) Light gray and pinkish marble, heavy- and thin-bedded	150
	(h) Cherty limestone with shales in the lower part	20
	(g) Gray marble	25
	(f) Shaly blue limestone	30
	(e) Gray marble holding *Solenopora* and ostracoda	10
	(d) Blue laminar limestone	17
	(c) Gray marble in several layers with shaly partings	15
	(b) White and pink, rather fine-grained marble	32
	(a) Thin- and heavy-bedded earthy siliceous limestones with nodules of black chert	50
1.	Knox dolomite:	
	White, yellowish and bluish-gray fine-grained argillaceous limestone. Unconformity marked by an uneven siliceous bed at the top	600

Knox dolomite.—The complete Knox section of this region is given on page 154. The greater part of this limestone is of the usual gray color and magnesian character, but the top, however, is unusual in that a white, argillaceous limestone is developed, portions of which, when analyzed, proved to have a composition worthy of notice in cement manufacture. Two samples selected to show possible extremes in composition gave the following upon analysis:

Analyses of white, argillaceous limestone, near top of Knox dolomite, Speer Ferry, Va.

(J. H. Gibboney, Analyst.)

	I.	II.
	Per cent.	Per cent.
Insoluble	34.62	12.34
Alumina (Al_2O_3), Iron oxide (Fe_2O_3)	4.72	2.34
Lime (CaO)	31.72	39.60
Calcium carbonate ($CaCO_3$)	56.64	70.72
Magnesia (MgO)	1.26	6.22
Magnesium carbonate ($MgCO_3$)	2.64	13.06
Total	98.62	98.46

Holston marble.—The various limestones and shales found with the Holston marble may be easily distinguished from associated strata by the unusually numerous fossils of rather peculiar type. Most conspicuous among these are the sunflower fossil *Receptaculites* and the ball cystid *Echinosphærites,* although massive and ramose bryozoa with unusually large cell openings, are common. As usual in this particular area of outcrop, the marbles are best developed near the bottom of the formation, while shales and shaly limestones occupy the middle and upper divisions. A variety of cement material ranging from pure limestones to typical shales is thus presented. Analyses of the various materials in the formation are tabulated below:

Analyses of Middle Ordovician limestones and shales, Speer Ferry, Va., section.

(J. H. Gibboney, Analyst.)

	I.	II.	III.	IV.	V.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Insoluble	0.86	39.52	33.80	10.56	10.10
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	1.10	5.64	4.36	2.24	2.36
Lime (CaO)	55.00	28.44	35.14	48.06	47.90
Calcium carbonate ($CaCO_3$)	98.21	50.70	59.18	85.82	85.72
Magnesia (MgO)	0.08	0.88	0.66	0.70	0.21
Magnesium carbonate ($MgCO_3$)	0.17	1.85	1.38	1.43	0.44
Total	100.34	97.71	98.72	100.05	98.62

I. Light-colored, coarsely crystalline marble, bed b of section.
II. Blue shale succeeding marbles (bed j).
III. Drab shales, middle portion of formation (bed j).
IV. Bluish argillaceous limestone, upper part of formation (bed l).
V. Dark argillaceous limestone, upper part of formation (bed k).

Moccasin limestone.—Probably the best development of these red-colored argillaceous limestones in southwestern Virginia is to be seen along the northern slope of Clinch mountain. At a number of places between Speer Ferry and Gate City, good outcrops may be found in close proximity to the railroad. At Speer Ferry the entire thickness and the lithological characters of the formation are well exposed in the cut leading to the new tunnel through Clinch mountain. The analysis of a sample from the vicinity of Speer Ferry varies but little from other analyses along this same line of outcrop.

Analysis of Moccasin limestone, vicinity of Speer Ferry, Va.

(J. H. Gibboney, Analyst.)

	Per cent.
Insoluble	34.28
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	4.96
Lime (CaO)	31.88
Calcium carbonate ($CaCO_3$)	56.92
Magnesia (MgO)	0.68
Magnesium carbonate ($MgCO_3$)	1.44
Total	97.60

Sevier shale.—These rocks outcrop well up on the slope on Clinch mountain, so that they are less accessible than the preceding two formations. However, in view of the great abundance of cement materials in the Holston limestones especially, the Sevier shale is less likely to be utilized. As usual the lower portion of these shales consists of thin-bedded dark blue limestone and calcareous shale, while higher the strata become quite sandy. This change in the character of the rock is shown in the following analyses:

Analyses of Sevier shale, vicinity of Speer Ferry, Va.

(J. H. Gibboney, Analyst.)

	I.	II.	III.
	Per cent.	Per cent.	Per cent.
Insoluble	7.08	33.40	55.60
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	1.88	4.92	7.60
Lime (CaO)	50.60	32.86	18.20
Calcium carbonate ($CaCO_3$)	90.36	58.68	32.50
Magnesia (MgO)	0.41	0.18	0.61
Magnesium carbonate ($MgCO_3$)	0.87	0.38	1.29
Total	100.19	97.38	96.99

I. Thin-bedded black limestone, lower (Trenton) horizon, Sevier shale.
II. Calcareous shales, lower (Trenton) horizon, Sevier shale.
III. Sandy shales, upper (Eden) horizon, Sevier shale.

Gate City Section.

Numerous exposures of the Ordovician limestone are found in the vicinity of Gate City, and a section of the rocks may be had along the Virginia and Southwestern railroad, starting at this town and going eastward through Big Moccasin Gap. Inasmuch as the cement material in this region is limited to the Ordovician limestones and shales, only that

part of the section is described. For abundance of material and transportation facilities the strip of Scott county lying between Moccasin ridge and Clinch mountain, and extending from Speer Ferry on the west to Gate City on the east, can hardly be surpassed in southwestern Virginia, for throughout this strip the railroad follows the line of outcrop of the Ordovician limestone closely. Unfortunately the strata along this area seldom contain argillaceous limestone of suitable composition for cement purposes without admixture, but since all grades of rock from pure limestone to shale are present, there should be no trouble in finding material for the necessary mixture.

The white argillaceous limestones near the top of the Knox are apparently not well shown in the vicinity of Gate City, the most conspicuous beds being the cherty middle division giving rise to Moccasin ridge. The Holston marble is better exposed and is associated, as at Speer Ferry, with shale and less crystalline limestone. Toward the bottom, the beds of marble are most conspicuous, while higher most of the strata are of blue flaggy limestone with interbedded shales. The following analyses are of the more argillaceous beds, but the purer limestones and calcareous shales have essentially the same composition as similar strata in the section at Speer Ferry.

Analyses of Holston limestone, Gate City, Va.

(J. H. Gibboney, Analyst.)

	I.	II.
	Per cent.	Per cent.
Insoluble	8.26	8.42
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3) }	1.82	3.66
Lime (CaO)	50.40	47.12
Calcium carbonate ($CaCO_3$)	90.89	84.14
Magnesia (MgO)	0.12	0.67
Magnesium carbonate ($MgCO_3$)	0.26	1.41
Total	101.23	97.63

I. Dark argillaceous limestone.
II. Blue argillaceous limestone.

In the vicinity of Gate City the Moccasin limestone is typically exposed and is made up of impure red clayey strata which reach a maximum thickness of 500 feet. As the analysis below shows it is of no value directly as a cement rock, but when mixed with purer limestone a suitable material might possibly be obtained.

Analysis of Moccasin limestone, Gate City, Va.

(J. H. Gibboney, Analyst.)

	Per cent.
Insoluble	32.24
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	4.50
Lime (CaO)	33.96
Calcium carbonate ($CaCO_3$)	60.64
Magnesia (MgO)	0.25
Magnesium carbonate ($MgCO_3$)	0.53
Total	97.91

The Sevier shale which follows the Moccasin limestone contains, as elsewhere along the west slope of Clinch mountain, thin limestone layers and calcareous shales in their lower part. These are the strata of most importance in this connection, and many of the layers approach a fair cement rock composition.

Analysis of calcareous shales, basal portion of Sevier shale, Gate City, Va.

(J. H. Gibboney, Analyst.)

	Per cent.
Insoluble	23.48
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	3.86
Lime (CaO)	39.44
Calcium carbonate ($CaCO_3$)	70.53
Magnesia (MgO)	0.09
Magnesium carbonate ($MgCO_3$)	0.18
Total	99.05

These more calcareous beds are followed by brown and yellow shales in which the lime content is much less, although for mixture with purer limestones the latter beds may serve very well. Higher in the Sevier shale more sandy material is found, thus precluding the use of the upper shales.

Analysis of upper part of Sevier shale, Gate City, Va.

(J. H. Gibboney, Analyst.)

	Per cent.
Insoluble	55.55
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	8.37
Lime (CaO)	18.41
Calcium carbonate ($CaCO_3$)	32.88
Magnesia (MgO)	0.72
Magnesium carbonate ($MgCO_3$)	1.51
Total	98.31

Following the Sevier shale are in order the Bays and Clinch sandstone, the latter forming the crest of Clinch mountain. As indicated before, neither of these need to be discussed as a cement rock.

Mendota Section.

The section here described lies on the northwestern side of Clinch mountain and therefore is situated in Russell county, although Mendota, the nearest railroad town, lies in Washington county. The rocks exposed in this section belong to the same line of outcrop as at Speer Ferry and Gate City in Scott county, and, as will be noted, the geologic succession is the same. These outcrops continue in a northeastward direction northwest of Clinch mountain throughout both of the counties mentioned. The second line of outcrops in these counties parallels the one just mentioned and in a general way follows Copper creek. Both of these strips at present have no railroad facilities at hand, so that, although the rock occurs in abundance, it is of interest mainly as a future source of supply.

Following the cherty and thin-bedded siliceous Knox dolomites in the Mendota section the first well exposed beds of the Holston are found to be light-colored, coarsely crystalline marble. These run high in lime and have essentially the same composition as the similar marbles in Scott county.

Continuing the section 120 feet of yellow shales with thin-bedded rubbly limestone succeed the marble. At the top of this division are about ten feet of more crystalline limestone. The shales contain numerous specimens of bryozoa and *Receptaculites*, while the ball cystid *Echinosphærites*, figured on plate XXI, is especially abundant.

Heavily bedded argillaceous limestone, amounting altogether to 35 feet in thickness, follow. Although a few of the layers contain a little chert, the strata as a whole have the best composition for cement rock of any noted in the section. A large massive bryozoan of the genus *Monotrypa* is particularly characteristic of this bed. The accompanying analysis is of a typical example of this argillaceous limestone:

Analysis of heavily bedded argillaceous limestone, Mendota section.

(J. H. Gibboney, Analyst.)

	Per cent.
Insoluble	9.48
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	2.34
Lime (CaO)	49.12
Calcium carbonate ($CaCO_3$)	87.71
Magnesia (MgO)	0.35
Magnesium carbonate ($MgCO_3$)	0.75
Total	100.28

In ascending order 150 feet of yellow and blue shales with blue limestone bands are found with fossils particularly abundant in the lower portion. These are followed by a second series of limestones which will prove of

value for cement purposes. Most of these limestones are thin-bedded and dove-colored. In the Mendota section a considerable portion of these beds is not exposed but they reach a thickness of several hundred feet. Fossils, particularly bryozoa, occur in great abundance, and many of the limestone slabs are covered with their remains. As will be noted from the analysis, the composition of this dove limestone is very similar to the argillaceous rock of the same section.

Analysis of dove limestone, Mendota section.

(J. H. Gibboney, Analyst.)	Per cent.
Insoluble	8.16
Alumina (Al_2O_3), Iron oxide (Fe_2O_3)	1.24
Lime (CaO)	49.76
Calcium carbonate ($CaCO_3$)	88.86
Magnesia (MgO)	0.75
Magnesium carbonate ($MgCO_3$)	1.58
Total	99.84

A red shaly limestone from the middle portion of the formation gave the following results on analysis:

Analysis of red shaly limestone, Moccasin formation, Mendota section.

(J. H. Gibboney, Analyst.)	Per cent.
Insoluble	28.86
Alumina (Al_2O_3), Iron oxide (Fe_2O_3)	4.40
Lime (CaO)	35.96
Calcium carbonate ($CaCO_3$)	64.26
Magnesia (MgO)	0.55
Magnesium carbonate ($MgCO_3$)	1.17
Total	98.69

The Sevier shale which succeeds the Moccasin has essentially the same characters in the Mendota section as elsewhere in southwestern Virginia. As usual the lower portion of this shale consists of thin limestone layers and calcareous shale. The analysis of the limestone bands is about the same as in other sections along this line of outcrop. A sample of the interbedded shales gave the following:

Analysis of calcareous shale, Sevier shale, Mendota section.

(J. H. Gibboney, Analyst.)	Per cent.
Insoluble	39.20
Alumina (Al_2O_3), Iron oxide (Fe_2O_3)	5.80
Lime (CaO)	29.20
Calcium carbonate ($CaCO_3$)	52.16
Magnesia (MgO)	0.07
Magnesium carbonate ($MgCO_3$)	0.15
Total	97.31

The red sandstones and shales of the Bays formation succeed the Sevier shale, and these in turn are followed by the Clinch sandstone exposed along the top of Clinch mountain. Neither these nor the succeeding formations of the section contain materials valuable for the manufacture of cement.

WISE COUNTY.

In the discussion of the general geology of Lee county, mention is made of the anticline occupying Powell valley. This anticline has its origin in the vicinity of Big Stone Gap, Wise county, and extends southwest for several hundred miles. Southwest of Big Stone Gap erosion has cut deeply enough into this fold to expose the Ordovician limestone and shales, and in this limited area only, in the county, can rocks from this horizon be had. The geologic section and composition of the rocks are essentially the same as in Lee county, and for this reason, as well as that the area of outcrop is comparatively small, samples for analysis were not taken. In the immediate vicinity and also several miles east of Big Stone Gap lies an area occupied by the Hancock limestone which may prove of economic importance in the future. With the exception of a small area about St. Paul the rest of Wise county is occupied by rocks of Carboniferous age.

DICKENSON AND BUCHANAN COUNTIES.

Both of these counties are underlaid by Coal Measures strata consisting of conglomerates, sandstones, shales, and coal beds. Calcareous matter is almost entirely wanting in these rocks, so that neither county will come under the present discussion. The detailed geology of the eastern half of Buchanan county has been mapped and described in the Tazewell folio (No. 44) of the U. S. Geological Survey, while the western half of the same county and nearly all of Dickenson county are included on the Grundy sheet.

WASHINGTON COUNTY.

In this county the outcrops of the Ordovician limestones and calcareous shales are found in two areas separated in a general way by Walker mountain. In each of these areas the geological succession of the rocks is different so that each area is here considered separately.

GEOLOGIC SUCCESSION EAST OF WALKER MOUNTAIN.

East of Walker mountain the Cambro-Ordovician dolomitic limestones are succeeded usually by the blue to black calcareous or sandy shales which in the Bristol folio of the U. S. Geological Survey have been mapped as the

Athens shale. These shales are here from 1,000 to 1,200 feet in thickness. Their main outcrops in Washington county are east of Bristol and Abingdon, where a number of small basins or troughs are occupied by them. As the easternmost part of the Valley is approached, the Athens shales become sandy, so that here they cannot be regarded as a possible source of cement material. The following analyses are of the more calcareous beds exposed to the west of these easternmost sandy outcrops.

Analyses of Athens shales, Washington county, Virginia.

(J. H. Gibboney, Analyst.)

	I.	II.	III.
	Per cent.	Per cent.	Per cent.
Insoluble	19.48	11.24	5.82
Organic matter	1.28	0.60	——
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3) }	1.28	0.96	0.54
Lime (CaO)	42.20	48.62	47.32
Calcium carbonate ($CaCO_3$)	75.36	86.82	84.50
Magnesia (MgO)	1.16	Tr.	4.16
Magnesium carbonate ($MgCO_3$)	2.45	Tr.	8.74
Total	99.85	99.62	99.60

I. Calcareous phase of Athens shale, 2 miles south of Abingdon, Va.
II. Athens shale, 3 miles east of Bristol, Va.
III. Limestone band in Athens shale, 4 miles east of Bristol, Va.

The detailed distribution of these shales in the western half of Washington county is indicated in the Bristol folio of the U. S. Geological Survey. In the eastern half of the county the region between Abingdon and the line of the Norfolk and Western railroad on the north, and the South Fork of the Holston river on the south is occupied by several long but narrow synclines in which a considerable thickness of Athens shale is developed. Locally a thin bed of blue to gray impure limestone correlated with the Stones River limestone of Tennessee is found at the base of these shales. The chemical composition of this limestone is often unfavorable for its use in the lime or cement industries.

Succeeding the Athens shale in the area east of Walker mountain is a series of thin-bedded sandstones and sandy shale, best developed along the extreme southeastern part of the Valley. This formation, the Tellico sandstone, named from the Tellico river in eastern Tennessee, is less than 300 feet in thickness and is developed only along the foothills of Holston and Iron mountains. The sandy nature of these strata, as well as the distance

of outcrop from the railroad, makes them of no economic importance.

Two samples of hydraulic limestones from the vicinity of Abingdon were analyzed under Professor Rogers' direction, and the results published in the "Geology of the Virginias." Judging from the locality, these samples were derived from the Knox dolomite. Their composition is as follows:

Analyses of Knox dolomite, near Abingdon, Va.

	I.	II.
	Per cent.	Per cent.
Calcium carbonate ($CaCO_3$)	19.55	15.30
Magnesium carbonate ($MgCO_3$)	2.54	7.11
Alumina (Al_2O_3), Iron oxide (Fe_2O_3)	0.28	0.23
Silica (SiO_2)	2.51	2.17
Water	0.12	0.19
Total	25.00	25.00

I. Bluish-gray limestone from locality a little south of Abingdon.
II. Dark blue limestone from locality 3 miles north of Abingdon.

GEOLOGIC SUCCESSION WEST OF WALKER MOUNTAIN.

With the exception of a few small and generally unimportant areas, the portion of Washington county west of Walker mountain is occupied by Paleozoic rocks younger than the Ordovician. Of these small areas where the Ordovician section is developed, the most important, from an economic standpoint, is along the western foothills of Walker mountain in the northeastern part of the county. The best and most continuous exposures of these rocks are found along the railroad from Glade Spring to Saltville, and a detailed section of this region is given below. Here the Knox dolomite is followed by from 100 to 200 feet of thick-bedded blue to gray slightly magnesian Stones River limestone, which, in turn, is succeeded by 300 feet of shales, here correlated with the Athens. Marbles and calcareous shales, 200 feet in thickness, follow the Athens shales, these two formations furnishing many layers having a fair composition for both cement and lime rock. Above the last mentioned formation are in ascending order 300 feet of red calcareous shales and impure limestones, 1,000 feet or more of yellow or dark shales, and 200 feet of red sandy shales and sandstones. These formations are more fully described in the following section, where analyses are also quoted. Commencing with the last mentioned group of strata, 200 feet of red sandy shales and sandstones, which may be found near the top of the western slope of Walker mountain in the eastern part of Washington county, the preceding formations are found in descending order in

bands paralleling Walker mountain. The entire width of outcrop of the important limestones and shales is here less than a mile, and the length of exposure unaffected by faulting is not more than eight miles. Proceeding southwestward, along the line of the Saltville fault, a narrow strip of Ordovician strata less than two miles in length is found in the southwest corner of the county, just northwest of Walker mountain. The formations of this strip have been mapped in detail by members of the U. S. Geological Survey, and the occurrence of good limestone at this point has been taken advantage of by Virginia capitalists. The section here is essentially the same as in the Glade Spring-Saltville area, the Holston marble furnishing the pure limestone.

The most important limestones and shales of Washington county are of Mississippian age. These outcrop in a continuous band two miles in width, crossing the county from southwest to northeast, east of the North Fork of Holston river, and west of Walker mountain. Analyses of these strata—the Newman limestone and Pennington shale—are given on a later page.

Sections illustrating the structure of the two areas of Ordovician strata are given on page 242.

Stratigraphy and Analyses of Rock in the Glade Spring-Saltville Area.

This region containing purer limestone and shale is of especial interest in possessing railroad facilities. Saltville lies on the north side of a great thrust fault with the lower beds of the Knox dolomite resting upon Mississippian gypsiferous shales. South of this fault the Cambrian and Ordovician limestones and shales as well as higher strata are encountered in regular order until, in the vicinity of Glade Spring, another great fault brings the Knox dolomite again in contact with the Mississippian shales. The Cambrian and Ordovician rocks of this succession are well shown along the railroad connecting Glade Spring and Saltville, and in the following geologic section only this portion is given because here alone are limestones and shales of economic interest found. This section commences just south of Saltville and continues to the Gap through Walker mountain.

Geologic section, Cambrian and Ordovician rocks, vicinity of Saltville, Va.

7. Bays sandstone. Red sandy shales and sandstones	200+
6. Sevier shale. Yellow and dark-colored shales with argillaceous limestone bands in lower part	1,000
5. Moccasin limestone. Red calcareous shales and impure argillaceous limestone	300
4. Holston marble and associated shale. Crystalline limestone (marble) with more or less calcareous shales	200+

3. Athens shale. Blue and black calcareous shales and argillaceous limestone	300
2. Stones River limestone. Thick-bedded, gray, somewhat magnesian limestone	100–200
1. Knox dolomite:	
More or less massive dolomitic limestone, sparingly cherty	1,500+
Massive dolomite weathering into an abundance of chert	500
Massive dolomite with little chert	500
Massive, slightly dolomitic gray limestone	500
Shaly limestone with more massive, non-dolomitic beds	500

Knox dolomite.—Just south of Saltville the great thrust fault with the lower beds of the Knox resting upon the Mississippian shales may be observed. The Knox then continues to outcrop along the railroad until a point about four miles south of Saltville, where the lowest beds of the Stones River limestone are seen. In this distance a thickness of at least 2,500 feet of limestone is seen arranged in the ascending order noted in the section. Immediately south of the Saltville fault are several hundred feet of shales with non-dolomitic limestone seams in which was found a trilobite fauna of Upper Cambrian age. Following these limestones and shales are 400 to 500 feet of similar but thicker bedded limestone running high in lime and low in magnesia as indicated in the analysis given below. Dolomitic strata with some chert succeed these purer limestones and continue for approximately 500 feet, when the chert becomes very abundant. Although this rock is fairly high in lime the magnesia content is also, as shown below, so high that it is of no value as a cement material. The upper 500 feet or more of the Knox is more dolomitic, but is still sparingly cherty.

The following analyses illustrate the range in composition of the Knox rocks in this section:

Analyses of Knox limestone, vicinity of Saltville, Va.
(J. H. Gibboney, Analyst.)

	I.	II.	III.
	Per cent.	Per cent.	Per cent.
Insoluble	2.54	3.98	3.62
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	0.78	1.12	0.48
Lime (CaO)	53.90	44.88	37.90
Calcium carbonate ($CaCO_3$)	96.25	80.14	67.68
Magnesia (MgO)	0.41	6.43	13.50
Magnesium carbonate ($MgCO_3$)	0.87	13.52	28.35
Total	100.44	98.76	100.13

I. Thick-bedded limestone (Upper Cambrian), lower portion of Knox, 2 miles south of Saltville, Va.
II. Dolomitic cherty limestone (Lower Cambrian), middle portion of Knox, about 3 miles south of Saltville, Va.
III. Dolomitic limestone (Beekmantown), upper part of Knox, 4 miles south of Saltville, Va.

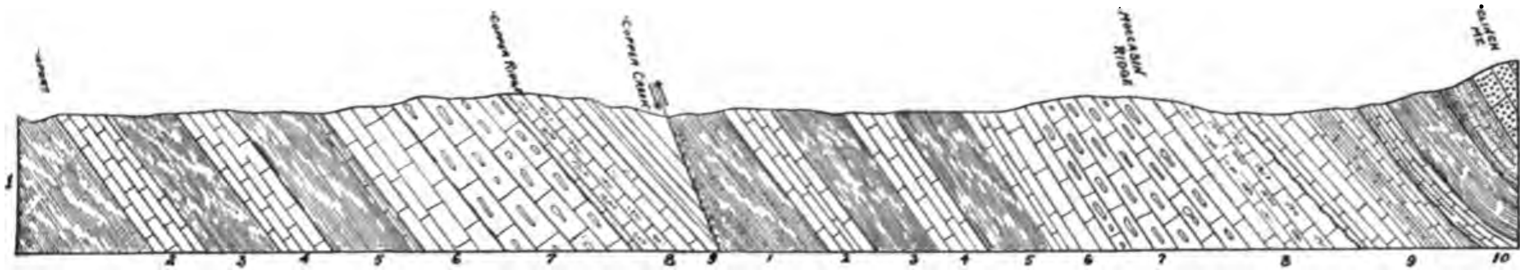


Fig. 25.—Structure section from Clinch Mountain west to Clinchport, Scott county, Virginia. 1. Russell shale. 2. Rutledge limestone. 3. Rogersville shale. 4. Maryville limestone. 5. Nolichucky shale. 6. Lower Knox dolomite. 7. Middle Knox dolomite. 8. Upper Knox dolomite. 9. Holston marble and associated shales. 10. Moccasin limestone. 11. Sevier shale. 12. Bays sandstone. 13. Clinch sandstone.

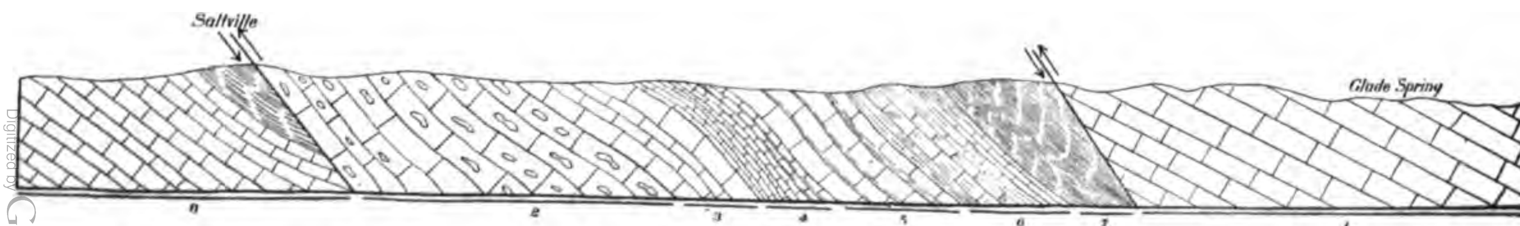


Fig. 26.—Structure section along railroad from Glade Spring to Saltville. 1. Cambrian limestone; 2. Knox dolomite; 3. Stones River limestone; 4. Athens shales; 5. Holston formation; 6. Moccasin limestone; 7. Sevier shale; 8. Carboniferous limestone and shale.

An analysis of a dolomitic limestone from the same general area has been published by Professor Rogers. The exact geological horizon of this limestone is unknown, but judging from the locality the sample was probably obtained from the lower Knox.

Analysis of bluish white, compact, hydraulic limestone, Rich Valley, Washington county, Virginia.

	Per cent.
Calcium carbonate ($CaCO_3$)	12.52
Magnesium carbonate ($MgCO_3$)	10.38
Alumina, tinged with oxide of iron	0.18
Silica (SiO_2)	1.85
Water	0.07
Total	25.00

Stones River limestone.—Just above the Knox dolomite the limestones of the succeeding formation, the Stones River, contain pebble-like plates and fragments of dolomite in a purer limestone matrix. Several feet above the contact a massive limestone bed is largely made up of such pebbles and fossils, the latter being in poor condition but indicating clearly the Chazy age of the rocks. The most conspicuous of these fossils are a laminar coral, *Stylarea parva* (Billings), and a large gastropod known as *Maclurea magna* (Billings).

In general the Stones River limestone in this section is thick-bedded, blue to gray in color and somewhat magnesian in composition. The range in the amount of magnesia present is expressed in the following analyses:

Analyses of Stones River limestone, 4 miles south of Saltville, Va.

(J. H. Gibboney, Analyst.)

	I.	II.
	Per cent.	Per cent.
Insoluble	4.60	7.34
Alumina (Al_2O_3) Iron oxide (Fe_2O_3)	0.24	0.88
Lime (CaO)	51.90	48.04
Calcium carbonate ($CaCO_3$)	92.68	85.78
Magnesia (MgO)	1.06	3.07
Magnesium carbonate ($MgCO_3$)	2.32	6.45
Total	99.84	100.45

Athens shale.—In southwestern Virginia east of Walker mountain the Stones River limestone is followed by blue and black calcareous shales

which in Tennessee has been designated the Athens shale. In the Saltville section, 300 feet of similar blue and black calcareous shales and argillaceous limestones follow the magnesian Stones River limestone, and, although the fossil evidence is meager, are probably the equivalent of the Athens shale. As the analyses indicate these shales approach good cement rock in composition more closely than any other strata in the section.

Analyses of Athens shale, about 5 miles south of Saltville, Va.

(J. H. Gibboney, Analyst.)

	I.	II.
	Per cent.	Per cent.
Insoluble	17.64	11.40
Organic matter	0.08	0.82
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3) }	1.40	1.38
Lime (CaO)	43.84	47.14
Calcium carbonate ($CaCO_3$)	78.28	84.18
Magnesia (MgO)	1.26	0.95
Magnesium carbonate ($MgCO_3$)	2.64	2.00
Total	100.04	99.78

Holston marble and associated shale.—The interval between the dark Athens shale and the comparatively red shales here referred to the Moccasin limestone is occupied by 200 feet or more of more or less coarsely crystalline marble and yellow calcareous shales. In the vicinity of Knoxville, Tenn., these beds have been distinguished from the general limestone series under the name of the Holston marble, and since they form a distinct group of rocks in Virginia, this designation is also adopted here. East of Clinch mountain in Virginia the Holston marble is seldom developed, but between that mountain and Powell mountain a considerable thickness may often be found. The marbles and shales hold the same faunas, so that they must be considered as belonging to the same formation. The relative development of the marble and shale is exceedingly variable. Often the shales are interbedded with the marble, but more frequently the marbles are best developed in the lower part of the formation. These strata are abundantly fossiliferous, many of the layers being crowded with bryozoa particularly.

These marbles in the Saltville area are as elsewhere essentially a pure limestone, so that no samples were analyzed. An unweathered specimen of the shales upon analysis gave the following composition:

Analysis of calcareous shale interbedded with Holston marble, 5 miles south of Saltville, Va.

(J. H. Gibboney, Analyst.)

	Per cent.
Insoluble	23.54
Alumina (Al_2O_3), Iron oxide (Fe_2O_3)	3.52
Lime (CaO)	39.86
Calcium carbonate ($CaCO_3$)	71.18
Magnesia (MgO)	0.88
Magnesium carbonate ($MgCO_3$)	1.78
Total	100.02

Moccasin limestone.—This formation consists of red argillaceous limestone and calcareous shales which might be suitable for a cement material if the following were an average analysis. However, the composition indicated happens to be of the best rock, most of the layers showing less favorably.

Analysis of argillaceous limestone, about 5 miles south of Saltville, Va.

(J. H. Gibboney, Analyst.)

	Per cent.
Insoluble	23.58
Alumina (Al_2O_3), Iron oxide (Fe_2O_3)	1.18
Lime (CaO)	40.34
Calcium carbonate ($CaCO_3$)	72.04
Magnesia (MgO)	0.83
Magnesium carbonate ($MgCO_3$)	1.74
Total	98.55

Sevier shale.—Only the lower part of the great shale which follows the Moccasin limestone is of value as a cement material. In the Saltville section these shales are about 1,000 feet in thickness and contain thin limestone bands and calcareous shales only in the lowest hundred feet. The analyses following are of typical unweathered specimens of these lower shales and limestones:

Analysis of limestones and shales, Sevier shale, Glade Spring section.

(J. H. Gibboney, Analyst.)

	I.	II.
	Per cent.	Per cent.
Insoluble	4.74	29.90
Alumina (Al_2O_3)	1.72	2.02
Iron oxide (Fe_2O_3)		1.30
Lime (CaO)	51.92	36.80
Calcium carbonate ($CaCO_3$)	92.71	65.72
Magnesia (MgO)	0.13	0.58
Magnesium carbonate ($MgCO_3$)	0.27	1.23
Total	99.44	100.17

I. Limestone band, lower part of Sevier shale, about 6 miles south of Saltville, Va.

II. Calcareous shales, lower part of Sevier shale, about 6 miles south of Saltville, Va.

Bays sandstone.—Sandy shales begin to appear in the upper part of the preceding formation and continue until the amount of sand becomes so great that a calcareous sandstone results. This merges into a formation which has been mapped in other parts of southwestern Virginia as the Bays sandstone, where the rocks consist of red sandy shales, sandstones or impure arenaceous limestones. As might be expected, the composition of these strata is such that no part of them is of value as a cement material. A sample from one of the sandy layers gave the following upon analysis:

Analysis of Bays sandstone, Glade Spring section.

(J. H. Gibboney, Analyst.)

	Per cent.
Insoluble	90.18
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	5.72
Lime (CaO)	0.64
Calcium carbonate ($CaCO_3$)	1.14
Magnesia (MgO)	0.03
Magnesium carbonate ($MgCO_3$)	0.07
Total	97.11

LEE COUNTY.

This county occupies the extreme southwest corner of Virginia, being situated in the angle between Kentucky and Tennessee. The Cumberland mountain with its northeast extension, Stone mountain, traverses the northwestern edge of Lee county, while the southeastern portion is occupied by

Wallen ridge, Powell mountain, and Newman ridge, with their narrow, intervening valleys. The most important valley of the county is that of Powell river which drains the greater portion of this section.

Three of the important faults of southwestern Virginia traverse Lee county. Commencing in the southeast portion, the Hunter valley fault enters the county from Tennessee and extends northeastward, passing just west of Newman ridge. Along this fault in the small portion of the county traversed, the Maryville (Cambrian) limestone is thrust usually against the Hancock (Silurian) limestone, but at some points lower formations of the Silurian may be found along its western side.

Between the line of the Hunter valley fault and the valley of Wallen creek occurs a continuous section of the various formations from the Hancock limestone on the east to the Knox dolomite in the valley on the west. The crest of Powell mountain is formed by the resistant Clinch sandstone, while the limestones of economic importance are found along the western foothills of this mountain and in the valley of Wallen creek. Proceeding northwestward across this valley the Knox dolomite is eventually found thrust upon either the Hancock limestone or Rockwood sandstone and shales. This point marks the Wallen valley fault which enters Virginia from Tennessee and continues northwestwardly to the head of the valley mentioned.

Crossing Wallen ridge, which, like Powell mountain, owes its preservation as a ridge to the Clinch sandstone, the underlying Bays sandstone and Sevier shale are encountered and finally, in the valley of Powell river, is found an anticline exposing the Ordovician limestone, with the Knox dolomite showing along the central portion. The Ordovician limestones are terminated on the west by the Poor valley fault passing southeast of Cumberland and Stone mountains. This fault is slight in the northeastern part of the county where the thrust is sometimes between portions of the same formation. Farther southwest, however, the Knox or higher Ordovician limestones are thrust against the Rockwood and still higher strata.

Three horizons in Lee county furnish raw material suitable for cement manufacture. The first and most important of these occupies the interval between the Knox dolomite and the Clinch sandstone, the second is the Hancock limestone of Silurian age, and the third comprises the Mississippian limestone and shale. On account of greater extent and more accessibility the Ordovician limestones are by far of greater importance and are therefore discussed in more detail. The Hancock limestone outcrops generally in small patches along the fault lines and is often cut out altogether. When

well exposed it is seen to be a blue limestone high in lime but becoming cherty toward the top. The maximum thickness in the Powell valley region was found to be 275 feet.

In this county the Ordovician rocks of value for cement purposes occur in two well defined areas. The less important of these is a strip brought up by the Wallen valley fault and following the western slope of Powell mountain along which these limestones and shales outcrop at a number of places. Although these rocks of this strip occur in quantity and usually have the proper chemical constitution for cement material, the distance of their outcrop from the railroad and their otherwise general inaccessibility cause them to be at present of little economic importance.

The second and more important area is bounded in a general way by Wallen ridge and Cumberland mountain, thus embracing the valley of Powell river. This valley in Lee county shows numerous outcrops of shales and pure argillaceous limestones of Ordovician age along its edges, the central portion being occupied mainly by the Knox dolomite. In the northern part of the northwestern half of the valley, the dove limestones immediately succeeding the Knox dolomite are faulted against Devonian black shale, all the intervening formations being thus cut out. Further south along the same side, faulting becomes less and less until finally the full sequence of strata may be observed. All along the southeastern edge, however, the succession of rocks seems to be normal, so that the full development of Ordovician limestones and shales may be found. The central portion of the valley, occupied by the Knox dolomite, averages several miles in width, but between this strip and Wallen ridge is an area of Ordovician shales and limestones of equal width.

An account of the general stratigraphy of this region is given on pages 176 to 186, in the discussion of the Powell valley area. Here also, generalized sections of the Ordovician rocks across the main bands of outcrop are introduced.

The most important outcrops of the post-Ordovician cement materials, the Hancock limestone and the Mississippian limestone and shale, are along the base of Cumberland mountain.

Details of localities.—The eastern third of Lee county is included in the Estillville quadrangle of the U. S. Geological Survey, so that a map of the detailed geology of this portion may be found in that folio. On account of the low dip of the rocks, in this portion of the county, almost the entire valley of Powell river is occupied by pure or argillaceous limestone, the Knox dolomite being limited to small strips. The limestones of this in-

Fig. 27.—Structure section from Bristol east to Holston Mountain. 1. Unicoi sandstone; 2. Hampton shale; 3. Honaker limestone; 4. Nolichucky shale; 5. Knox dolomite; 6. Athens shale; 7. Tellico sandstone.

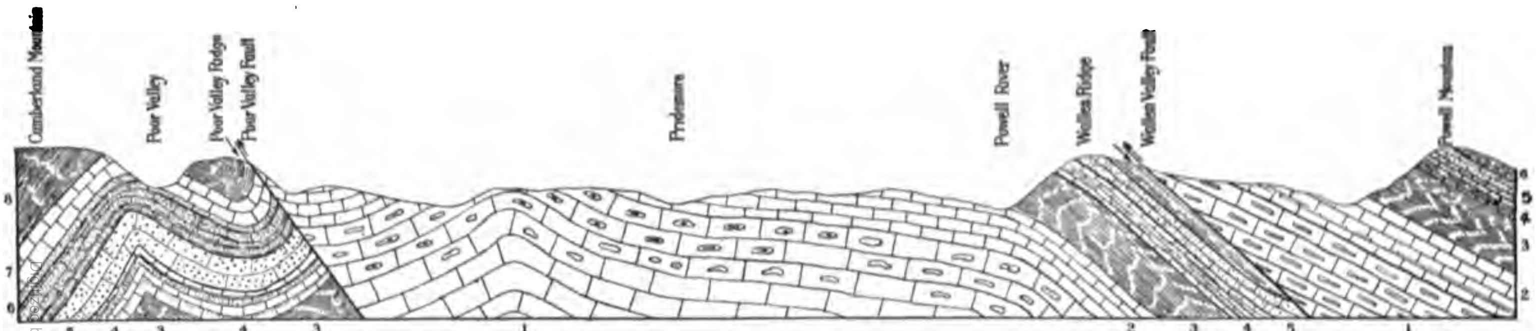


Fig. 28.—Structure section across Lee county, from Powell mountain north to Pridemore; thence northeast to Cumberland mountain. 1. Knox dolomite. 2. Middle Ordovician limestone (Stones River—Trenton). 3. Sevier shales (Utica and Eden). 4. Lorraine (Bays) limestone and sandstone. 5. Clinch sandstone. 6. Rockwood shale and sandstone.

terval have been mapped as a unit under the name of Chickamauga limestone, while the shale division of the Upper Ordovician is designated the Sevier shale. The same arrangement exists throughout the rest of this valley with the exception that the Knox areas increase in width going west and southwest. To show the general arrangement of the strata in this area, a structure section from Powell mountain on the south, across Wallen ridge and the Powell river valley in the vicinity of Pridemore to the Cumberland mountain on the north, is introduced.

Although there are numerous outcrops of limestone throughout this area, samples for analysis were taken only at such points where the transportation facilities were near at hand. The analyses from these localities mentioned below may, however, be considered as typical for the entire region.

Ben Hur, Va.—Two fairly complete sections ranging from the Lower Chickamauga rocks to the Devonian black shale are exposed in this vicinity along the Louisville and Nashville railroad. Beginning at the railroad station, where the fault between the Tyrone limestone and Devonian black shale is well shown (see plate I, figure 1), the following sequence of rocks is seen, proceeding west along the railroad. The division numbers and correlations are the same as given on pages 177 to 186.

Geologic section just west of Ben Hur, Va.

	Feet.
Rockwood formation:	
Red sandstone and sandy shales with seams of iron ore	——
Bays (Lorraine) formation:	
Nodular shaly limestone full of *Hebertella sinuata*	5
Finely granular light gray limestone with thin clay seams	2
Red clayey limestone	35
Yellow and red calcareous shales	150
Arenaceous limestone and shales, interbedded	80
Sevier (Eden) shale:	
Olive and yellow shales holding *Rafinesquina alternata, R. squamula, Calymene*, and *Zygospira*	300
Chickamauga limestone:	
Division 5.	
Subgranular grayish-blue limestone interbedded with yellow shale	43
Fine-grained, light gray, thin-bedded limestone with shaly partings	73
Division 4.	
Granular blue limestone	50
Alternating layers of granular and fine-grained limestone	200
Division 3.	
Yellowish to light chocolate-colored shales	150
Division 2.	
Yellow clayey limestone	100
Finely granular thin white clayey limestone	50
Shales and shaly limestone	200
Fairly pure subgranular light-colored and dove limestone	50

Knox dolomite.—The upper or Beekmantown portion of this Cambro-Ordovician limestone occupies the central portion of the valley. As usual this part of the Knox dolomite is a gray magnesian limestone, which upon weathering leaves a residual mantle of chert. This chert and the characteristic red color of the soil makes the recognition of Knox areas comparatively easy. Although fossils are usually rare, gastropods and cephalopods of Beekmantown age are found in the chert.

Division 1.—Following the cherty Knox are about 350 feet of rather heavy-bedded dove limestone which holds fossils, indicating that these strata are the equivalents of the Stones River of central Tennessee and Kentucky. The limestones of this formation run high in calcium carbonate, as a rule, but, as the analyses in the following table show, a considerable variation in composition may be expected. The samples analyzed were collected in the valley east of Ben Hur, the strata of division 1 not being included in the foregoing Ben Hur section.

Analyses of massive dove limestones, division 1 of Chickamauga limestone, Ben Hur, Va.

(J. H. Gibboney, Analyst.)

	I.	II.
	Per cent.	Per cent.
Insoluble	7.22	17.80
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3) }	2.68	1.16
Lime (CaO)	49.26	43.66
Calcium carbonate ($CaCO_3$)	87.96	77.57
Magnesia (MgO)	0.68	1.11
Magnesium carbonate ($MgCO_3$)	1.43	2.33
Total	99.29	98.86

Division 2.—Upon fresh exposures these strata have all the appearance of a massive, more or less pure dove limestone, but, when weathered, shaly materials are noted to make up a fair percentage of the rocks. This resemblance to a pure limestone is borne out by analyses of the freshly quarried rock, three examples of which were found to have the following composition:

Division 4.—Massive granular and in most cases comparatively pure limestones follow the shales of division 3, thus placing side by side the essential materials for cement manufacture. Four samples from different horizons of the division gave the following composition:

Analyses of Chickamauga limestone, division 4, Ben Hur, Va.

	I.	II.	III.	IV.
	Per cent.	Per cent.	Per cent.	Per cent.
Insoluble	8.56	1.22	6.93	5.40
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	1.68	1.53	1.94	2.20
Lime (CaO)	50.28	——	49.11	48.70
Calcium carbonate ($CaCO_3$)	89.48	84.07	87.69	86.96
Magnesia (MgO)	0.08	——	1.36	2.42
Magnesium carbonate ($MgCO_3$)	0.17	2.01	2.86	5.06
Total	99.89	88.83	99.42	99.62

I. J. H. Gibboney, analyst.
II–IV. Wm. M. Thornton, Jr., analyst.

Division 5.—Interbedded with the limestones of this division are shale bands which because of a consequent lack of uniformity in composition causes the strata to be of less importance than the preceding more massive limestones. Samples of the thin limestones of division 5 showed the following composition upon analysis:

Analyses of Chickamauga limestone, division 5, Ben Hur, Va.

(Wm. M. Thornton, Jr., Analyst.)

	I.	II.	III.	IV.	V.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Insoluble	14.00	8.38	7.76	2.69	11.97
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	2.36	3.61	2.88	1.28	4.54
Lime (CaO)	36.40	——	48.40	50.13	43.61
Calcium carbonate ($CaCO_3$)	82.86	85.60	86.43	89.51	77.87
Magnesia (MgO)	0.05	——	1.11	2.25	0.87
Magnesium carbonate ($MgCO_3$)	0.11	1.80	2.31	4.70	1.84
Total	99.33	99.39	99.38	98.18	96.02

Sevier shale.—The Sevier shale of the Powell valley area has been discussed on a previous page, so that it is necessary to introduce here only

analyses of these strata in Lee county. The upper part of the Sevier shale is usually too sandy for use as a cement material, but the lower beds are more favorable in composition. A sample of the thin, coarsely crystalline limestone interbedded with the shale gave the composition shown in analysis I, while that of the shale itself is given under II.

Analyses of limestone and shale, Sevier shale, Ben Hur, Va.

(Wm. M. Thornton, Jr., Analyst.)

	I.	II.
	Per cent.	Per cent.
Silica (SiO_2)	7.13	54.67
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3) }	6.83	17.64
Magnesia (MgO)	2.26	1.77
Lime (CaO)	45.44	11.14
Magnesium carbonate ($MgCO_3$)	4.69	3.70
Calcium carbonate ($CaCO_3$)	81.14	19.89
Total	99.79	95.90

Bays (Lorraine) formation.—The various strata comprised in the Bays formation of Lee county are noted in the section on another page, from which the samples giving the following analyses were selected:

Analyses of limestone, Bays formation, Ben Hur, Va.

(Wm. M. Thornton, Jr., Analyst.)

	I.	II.	III.
	Per cent.	Per cent.	Per cent.
Insoluble residue	30.33	30.16	56.44
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3) }	9.71	12.92	9.68
Calcium carbonate ($CaCO_3$)	45.96	44.34	29.02
Magnesium carbonate ($MgCO_3$)	12.55	8.48	2.14
Total	98.55	95.90	97.28

I. Blue clayey limestone.
II. Dark argillaceous limestone.
III. Reddish arenaceous limestone.

A more detailed section of these strata is shown northeast of the railroad station at Ben Hur.

Geologic section along Louisville and Nashville railroad, just northeast of Ben Hur, Va.

	Feet.
Devonian black shale (exposed at station)	——
Hancock limestone, not well exposed	——
Rockwood formation:	
Red sandstones and sandy shales	——
Clinch sandstone:	
Loose blocks of white sandstone, possibly belonging to Rockwood formation	——
Bays (Lorraine) formation:	
Clayey, red and yellow limestone without fossils	40
Massive nodular blue limestone with large massive ramose bryozoa and *Orthorhynchula linneyi*	5
Clayey, unfossiliferous yellow and blue limestone	32
Nodular blue limestone with ramose bryozoa and *Hebertella sinuata*	20
Sandy and argillaceous limestone	2
Nodular limestone full of *Hebertella sinuata*	6
Red and blue clayey limestone	14
Nodular blue limestones and shales full of *Hebertella sinuata* and *Orthorhynchula linneyi*	50
Shaley limestone crowded with bryozoa	12
Slightly arenaceous limy shales and limestones with few fossils	28
Thin-bedded limestones and shales with numerous fossils	21
Thin limestones alternating with blue shale	17
Arenaceous and clayey limestone with seams of shale	18
Olive shales with numerous clayey limestone seams	95
Subgranular bluish limestone with numerous fossils	68
Sevier (Eden) shale:	
Olive and brown shales with sandy layers	——

A portion of the Hancock limestone is exposed along the Louisville and Nashville railroad just northeast of the station at Ben Hur. Samples from these outcrops were analyzed with the following results:

Analyses of Hancock limestone, Ben Hur, Va.

(Wm. M. Thornton, Jr., Analyst.)

	I.	II.	III.
	Per cent.	Per cent.	Per cent.
Silica (SiO_2)	1.80	1.67	3.15
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3) }	0.71	1.06	2.29
Magnesia (MgO)	2.71	2.60	19.04
Lime (CaO)	51.52	51.58	30.84
Magnesium carbonate ($MgCO_3$)	5.66	5.31	39.80
Calcium carbonate ($CaCO_3$)	92.01	92.12	55.08
Total	100.18	100.16	100.32

Pennington Gap.—In the immediate vicinity of this town the lower divisions of the Chickamauga limestone are well represented, although the structure of the rocks is made out with some difficulty. Evidence of several folds exposing small synclines of limestones belonging to division 2 is present in the numerous outcrops of the area, while northwestward along the Black mountain railroad, two if not three faults with small thrusts may be noted. Proceeding northwestward along this railroad, the rocks occur in ascending order until the Lee conglomerate is encountered in the Gap itself.

The subdivisions of division 1 of the Chickamauga limestone at Pennington Gap have been noted on a previous page, where correlations with the Stones River formation in its type area—central Tennessee—are given. The lithologic characters of this section in Virginia are as follows:

Section of Chickamauga limestone, division 1, Pennington, Gap, Va.

	Feet.
Chickamauga limestone:	
Division 2. Thin-bedded dove and clayey limestone	—
Division 1. Dove and blue strata, arranged as follows:	
(d) Thin-bedded dove limestone	85
(c) Finely granular bluish dove or gray limestone	45
(b) Red shaly limestone	15
(a) Compact dove limestone at top and light gray limestone beneath with a cherty bed	200+
Total	345

An average sample from the thin-bedded dove limestone at the top of division 1 gave the usual high lime content characteristic of this type of rock.

Analysis of thin-bedded dove limestone, Pennington Gap, Va.

(Wm. M. Thornton, Jr., Analyst.)

	Per cent.
Insoluble residue	2.67
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	2.78
Calcium carbonate ($CaCO_3$)	93.25
Magnesium carbonate ($MgCO_3$)	1.28
Total	99.98

The red shaly limestone associated with these rather pure dove strata, and forming bed *c* of the section, contains an unusually large amount of calcium carbonate for such material, although, as indicated in the analysis, the silica and iron-alumina content is more in keeping with clayey rock.

Analysis of red shaly limestone, bed c of section, Pennington Gap, Va.

(Wm. M. Thornton, Jr., Analyst.)

	Per cent.
Insoluble residue	6.17
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3) }	3.89
Calcium carbonate ($CaCO_3$)	87.53
Magnesium carbonate ($MgCO_3$)	2.13
Total	99.72

Just south of the Gap, the Cumberland mountain band of Pennington shale outcrops. The samples from which the following analyses were made were collected at exposures along the Black Mountain railroad:

Analyses of Pennington shale, Pennington Gap, Va.

(Wm. M. Thornton, Jr., Analyst.)

	I.	II.
	Per cent.	Per cent.
Silica (SiO_2)	61.33	55.65
Alumina (Al_2O_3)	18.74	21.43
Iron oxide (Fe_2O_3)	6.73	6.71
Magnesia (MgO)	1.46	1.52
Lime (CaO)	0.40	0.47
Manganese oxide (MnO)	0.02	0.50
Loss on ignition	7.73	10.88
Total	96.41	97.16

POST-ORDOVICIAN CEMENT MATERIALS

INTRODUCTION.

Most of the major geological divisions of post-Ordovician age in western Virginia contain limestones or shales of possible value as cement materials, but the location and composition of these strata are much less favorable than the rocks discussed in the foregoing pages. It is, therefore, hardly necessary to discuss the stratigraphy of these younger rocks in the detail accorded the older formations, but in order to show the geologic succession and character of the strata, the accompanying table of formations is introduced. Columnar sections illustrating the complete stratigraphy of the various parts of Appalachian Virginia have been given on former pages (see figures 2, 16 and 17). Reference to the table on page 259 will show that the Lewistown limestone of late Silurian and early Devonian age, and the Greenbrier limestone of the Mississippian period or their equivalents are the only important limestone formations following the Ordovician rocks.

LEWISTOWN LIMESTONE.

Immediately overlying the Silurian (Rockwood) sandstones and arenaceous shales and preceding the Devonian shales in this part of the Appalachian district, limestones varying in thickness up to 1,050 feet are sometimes found. These limestones are of Cayugan and Helderbergian age, but have been mapped under several names. In northwestern and central western Virginia this formation has been designated the Lewistown limestone, while strata occupying the same stratigraphic position in the southwestern part of the state have been called the Hancock limestone. In Giles and neighboring counties of southwestern Virginia, these limestones form a part of the Giles formation. The Lewistown limestone is well known as a source of cement material, and therefore all of these Helderbergian limestones are here described under that general name. The most important areas of outcrop are indicated on the accompanying map.

The lithology and thickness of the Lewistown formation varies considerably even in small areas. In general these limestones are thin-bedded and shaly below, massive in the middle portion, and cherty or sandy above; consequently the lower and middle portions are of most importance as a cement rock. The cherty upper beds are massive and give rise to ridges,

Table of Post-Ordovician formations in Appalachian Virginia.

Period.	Rogers.	Northwestern and central western Virginia.	Max. thickness in feet.	Southwestern Virginia (Northern half).	Max. thickness in feet.	Southwestern Virginia (Southern half).	Max. thickness in feet.
Pennsylvanian	No. XIII—Lower coal group			Tellowa sandstone, etc. Sequoyah sandstone, etc.	500 450		
	No. XII—Great conglomerate			Dotson sandstone Bearwallow conglomerate Dismal sandstone, etc. (Dismal conglomerate lentil) Raleigh sandstone Welch sandstone, etc. Pocahontas sandstone, etc.	180 60 490 120 100 700 360	Harlan sandstone Wise sandstone, etc. Gladeville sandstone Norton sandstone, etc. Lee conglomerate	880 1260 120 1300 1500
Mississippian	No. XI { Greenbrier shale			Bluestone sandstone, etc. Princeton conglomerate Hinton sandstone, shale, etc. *Bluefield shale	800 40 1250 1250	*Pennington shale	1100
	No. XI { Greenbrier limestone			*Greenbrier limestone	1000	*Newman limestone	1000
	No. X—Montgomery grits	Pocono sandstone	700	Price sandstone	200	Price sandstone	300
Devonian	Nos. IX and VIII { Catskill, Chemung, Portage, Genesee, Hamilton, Marcellus	Hampshire sandstone Jennings shale and sandstone	1800 3800	Kimberling sandy shale, etc. *Romney black shale	3000 500	Grainger sandy shale *Chattanooga black shale	500 1000
	Nos. VII and VI { Oriskany, Lower Helderberg	*Romney black shale Monterey sandstone *Lewistown limestone	1300 300 } 1050	Giles sandstone and cherty limestone	} 250	*Hancock limestone	275
Silurian	No. V—Clinton No. IV—Medina	*Lewisto'n shaly limestone Rockwood sandstone, etc Massanutten sandstone: Cacapon member Tuscarora member	 900 630 300	*Giles shaly limestone Rockwood sandstone, etc. Clinch sandstone		Rockwood sandstone, etc. Clinch sandstone	670 250

* Strata of possible use for cement material.

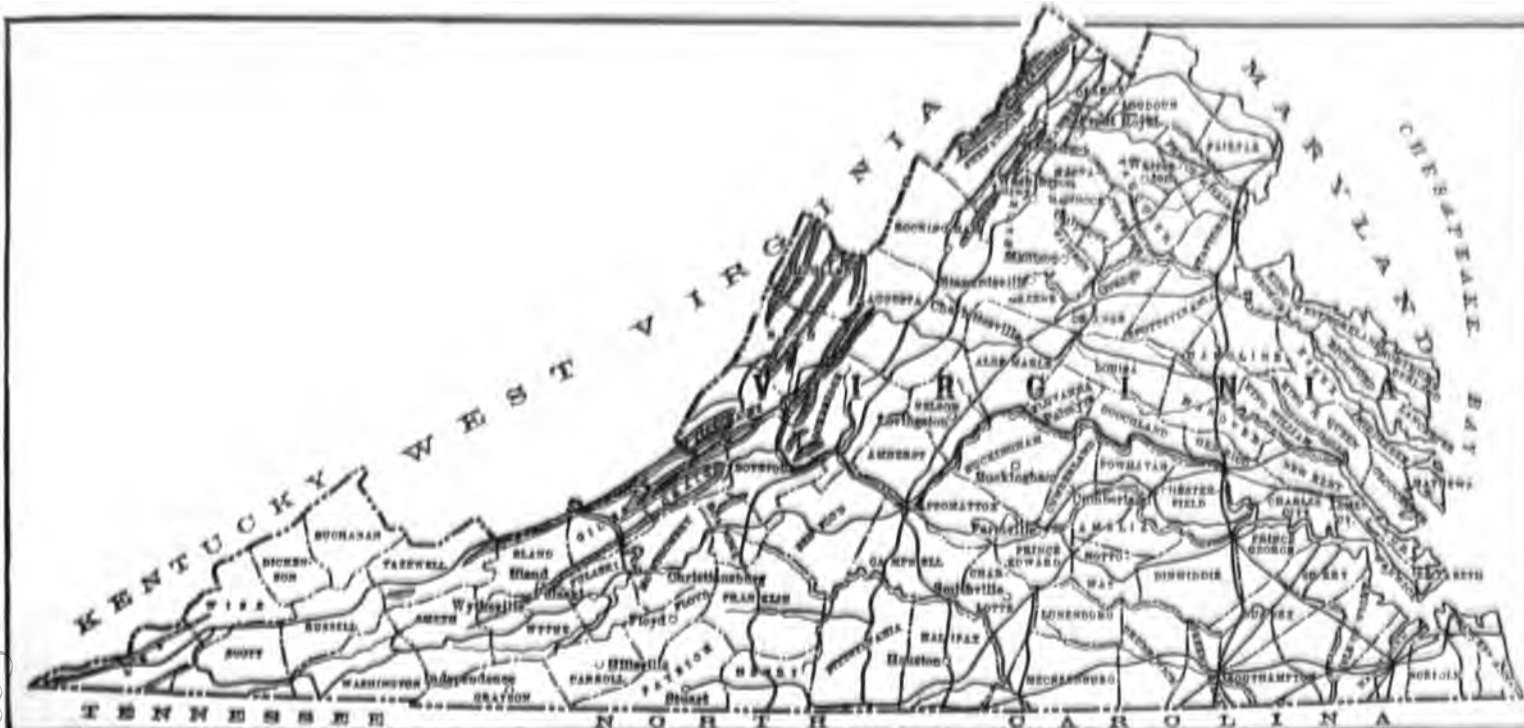


Fig. 29. Map of Virginia showing distribution of principal areas of Lewistown limestone. The width of these areas of outcrops is exaggerated.

Anticline in Lewistown limestone with capping of Monterey sandstone, showing occurrence along mountain slope. North Fork of the Potomac river, 2 miles south of Hopeville, W. Va. (Photo by N. H. Darton.)

ANTICLINE IN LEWISTOWN LIMESTONE.

as shown in plate XXVII, but the lower members are usually more favorably located. The middle beds are made up of light-colored coarsely crystalline, fossiliferous strata, a few shaly limestones, and at the bottom, dark-colored rock, while the lower portion contains for the most part thin, flaggy limestones, the individual layers of which readily separate with smooth surfaces. The formation as a whole, therefore, is seen to be composed of argillaceous and calcareous strata, of which a considerable portion can be employed in the manufacture of cement. The basal flaggy limestone is usually of greater thickness than the other members combined, and this fact, together with its favorable composition, would seem to make it of most importance as a cement rock, but unfortunately the interbedded shales differ so greatly upon analysis that the value of the rock as a whole is much decreased.

General distribution.—It will be noticed from a glance at the accompanying map that the more extensive areas of Lewistown limestone are located in the western part of central western Virginia. A portion of this area is mapped in detail in the Monterey, Staunton, and Franklin folios (numbers 61, 14, and 32, respectively) of the U. S. Geological Survey.

In northwestern Virginia two areas of outcrop are found. The easternmost is a narrow strip brought up by the Massanutten mountain syncline. This has been mapped by A. C. Spencer.[a] The western area occupies portions of Shenandoah and Frederick counties in the vicinity of North and Little North mountains.

Narrow strips of the Giles and Hancock formations are found west of the Appalachian Valley in southwestern Virginia. These outcrops generally follow the mountains or are brought up along the great faults. In either case the outcrops, almost without exception, are so far from transportation facilities, or the rock is of such a poor quality, that this limestone in southwestern Virginia cannot be regarded as a very promising future source of cement rock. The Giles and Hancock formations are mapped in the Pocahontas (26), Bristol (59), Tazewell (44), and Estillville (12) folios of the U. S. Geological Survey.

Paleontology.—The Lewistown limestone usually contains numerous fossils, which will cause its identification to be comparatively easy where the stratigraphic succession is obscured. The lower shaly portion of thin-

[a]The Geology of Massanutten Mountain in Virginia. Washington, D. C., 1897.

These figures are natural size and are copied from various authors.

Figs. 1, 2.—*Atrypa reticularis* (Linnæus). Dorsal and side views of the variety occurring in the Lewistown limestone. This shell is distinguished by its elongate, gibbous form, and finely plicate surface, which is without strong concentric growth lines.

Figs 3, 4.—*Leptæna rhomboidalis* (Wilckens). A view of a ventral valve, natural size. Side view of a strongly geniculated specimen.

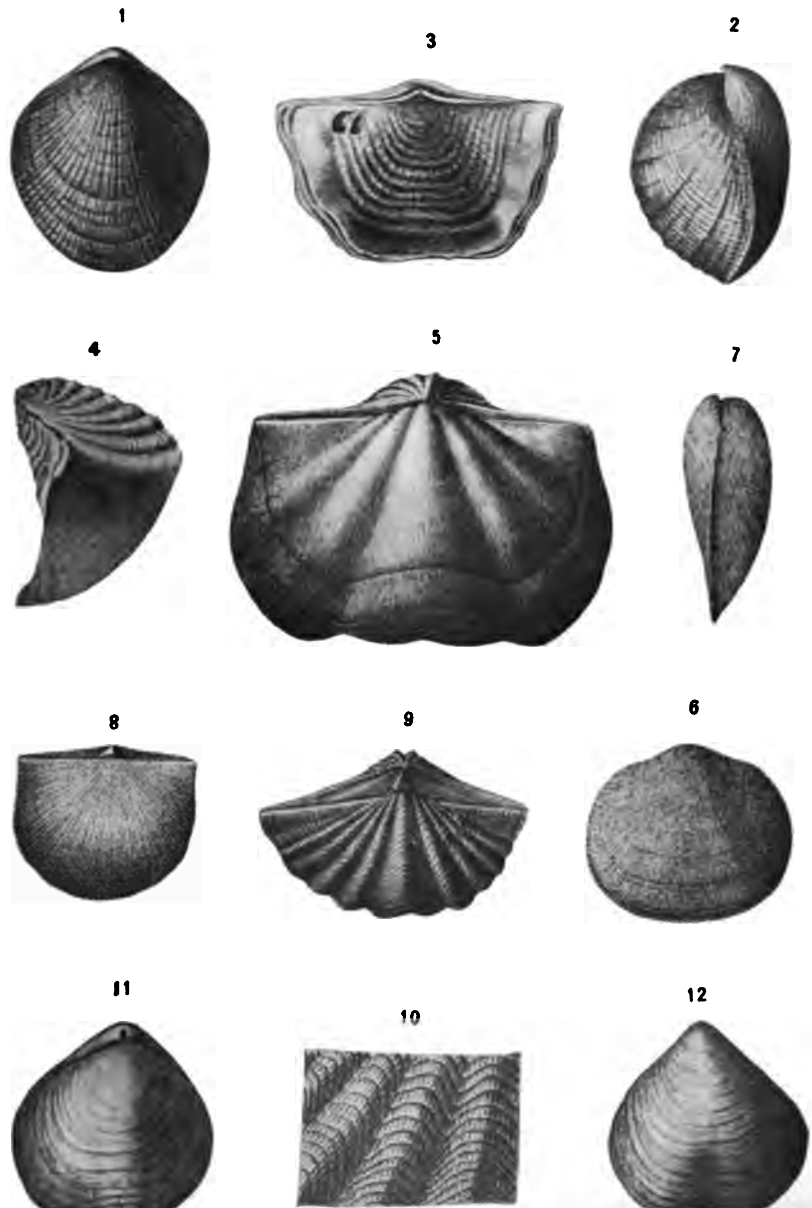
Fig. 5.—*Spirifer macropleura* (Conrad). A dorsal view of a normal individual. The low, finely striated, broad folds are especially characteristic.

Figs. 6, 7.—*Rhipidomella oblata* (Hall). Ventral view of an average specimen, and an edge view of a very large example.

Fig. 8.—*Schuchertella woolworthana* (Hall). The dorsal side of this shell, slightly reduced in size.

Figs. 9, 10.—*Spirifer (Delthyris) perlamellosus* (Hall). View of a normal example, natural size, and surface of same enlarged. The crowded, radially striated lamellæ readily distinguishes this form.

Figs. 11, 12.—*Meristella arcuata* (Hall). Dorsal and ventral views of an ordinary shell of this species.



BRACHIOPODS OF THE HELDERBERGIAN DIVISION OF THE LEWISTOWN LIMESTONE.

found at Seven Fountains and in the stream beds on either side of Middle mountain. Spencer[a] has published the following section of these rocks:

Section of Lewistown limestone in the vicinity of Seven Fountains.

	Feet.
Dark fissile shale (Romney shale)	——
Coarse conglomerate (Monterey sandstone)	1
Shale, yellow	6
Limestone, fossiliferous blue, beds 6 inches to 3 feet	25
Limestone, gray, earthy	2
Limestone, shaly, much chert	20
Limestone, compact, gray	10
Clay shale, variegated, limy	30
	94

The fossiliferous blue limestone of this section gave the following upon analysis:

Analysis of blue limestone, Lewistown formation, Seven Fountains, Va.

(J. H. Gibboney, Analyst.)

	Per cent.
Insoluble	5.76
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3) }	0.52
Lime (CaO)	50.88
Calcium carbonate ($CaCO_3$)	90.86
Magnesia (MgO)	1.12
Magnesium carbonate ($MgCO_3$)	2.36
Total	99.50

HIGHLAND AND BATH COUNTIES.

In central western Virginia west of the Appalachian Valley, the various anticlines and synclines afford rather numerous strips of outcrop of the Lewistown limestone. Moreover, in this area the formation reaches its greatest development and here also the railroad facilities are best. Therefore, from an economic standpoint, this part of the state is most promising. In the Monterey and Staunton folios of the U. S. Geological Survey, descriptions and maps of the Lewistown formation are given, and the following descriptions of the rocks and section are quoted from the former:

"The formation consists of limestones which are cherty, shaly, and sandy above, more massive in the middle, and thin-bedded or slabby below. The proportion of chert in the upper beds diminishes to the south, but the presence of a cherty member at the top of the formation is always characteristic. Next below there are usually alternations of shaly limestones, which to the southeast contain some very sandy layers. There are also in-

[a] Op. cit.

cluded some thicker layers of purer limestone. The middle members are irregular in character and vary greatly from place to place. A very characteristic member near the center of the formation is a dark-blue, wavy-bedded, massive limestone 50 to 60 feet thick, merging upward into harder, sandy limestone and hard, massive limestone with thin streaks of chert. At its base there is usually a distinct coralline bed. The lower half of the formation consists of slabby limestone merging down into an irregular series of alternations of calcareous shales and impure limestones. In one portion of the area this lower series contains a very sandy bed 15 to 20 feet thick, 50 or 60 feet above the base of the formation. The series of flaggy beds which constitute so large a portion of the formation are quite pure limestones, dark on fresh fracture but weathering lighter on exposure. The beds are mainly from one-half to two inches thick, with smooth surfaces, along which the layers readily separate. To the southeast the upper part of the formation includes, just below the cherty beds, a very pure, massive, fossiliferous, semicrystalline limestone.

"The thickness of the Lewistown limestone averages about 900 feet over the greater part of the Monterey quadrangle, but to the extreme southeast it decreases to about 600 feet. In the vicinity of Monterey a number of fairly satisfactory measurements indicated a thickness of about 900 feet. Two measurements in Back Creek mountain east of Mountain Grove were 1,080 and 1,100 feet. At Lower Gap a fairly satisfactory series of exposures show about 850 feet of Lewistown beds. At Panther Gap the thickness is 550 feet. On Cowardin Run, in the ridge lying on the west side of Warm Springs Valley, 710 feet were measured; and in the gap west of Hot Springs the amount appears to be slightly less than this. One of the most complete exposures of the formation is on the turnpike from Warm Springs to Mountain Grove, on the first slopes west of Jackson river, where a thickness of 1,080 feet was measured. There are a number of small intervals covered by débris, but the greater part of the formation is clearly exposed, as follows:

Section on road from Warm Springs to Mountain Grove, west of Jackson river.

	Feet.
At top, alterations of impure and shaly limestones, fossiliferous	460
Wavy-bedded, massive limestone with coralline bed at base	?
Slabby limestone	400
Calcareous shale	25
Massive fine-grained sandstone, weathering light buff; probably cement rock	15
Sandstone	4
Shaly material	—
Sandstone and sandy beds	20
At bottom, buff shales and thin, dark, semicrystalline limestone layers	100

"At the top there is considerable cherty débris, and two beds of massive blue limestone overlain by the Monterey sandstone, which extends down the slope to Jackson river."

Samples from the upper beds of this formation were collected for analysis. Reference to the two folios mentioned will show the distribution of these limestones so that detailed descriptions of these areas need not be given.

Analyses of Lewistown limestone, Warm Springs-Mountain Grove section.

(J. H. Gibboney, Analyst.)

	I.	II.
	Per cent.	Per cent.
Insoluble	14.68	19.12
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3) }	1.26	2.70
Lime (CaO)	43.96	42.12
Calcium carbonate ($CaCO_3$)	78.50	75.21
Magnesia (MgO)	2.09	1.09
Magnesium carbonate ($MgCO_3$)	4.40	2.30
Total	98.84	99.33

I. Impure fossiliferous limestone.
II. Shaly limestone.

Craigsville.

Commencing at Pond Gap and continuing for some miles southwest the Lewistown limestone outcrops either very close to the Chesapeake and Ohio railroad or is crossed by it. This region therefore is of particular importance, and the favorable location of good cement rock and railroad facilities have been taken advantage of in the establishment of a Portland cement manufactory at Craigsville. This plant, the property of the Virginia Portland Cement Company, is of note in that it is the only well established Portland cement manufactory in the state. A description of the plant, by F. H. Lewis, is given in "The Cement Industry," while additional notes may be found later on in the present volume. A section and analyses of the limestone and shale may be found in Bulletin No. 225 of the U. S. Geological Survey.[a] For completeness, these are repeated below:

"The beds which go to make up No. 6 Rogers, the Lower Helderberg limestone, are well developed there [at Craigsville] in the following order measured from below:

[a] Catlett, Charles, Cement Resources of the Valley of Virginia.

Section near Craigsville.

		Feet.
1.	Layer heavy fossiliferous limestone passing into sandstone	——
2.	Very dark slaty siliceous limestone	10
3.	Gray fossiliferous limestone	10
4.	Dark, irregular siliceous magnesian limestone	2 to 20
5.	Gray, soft, highly fossiliferous limestone	30 to 50
6.	Dark, close-grained limestone of varying thickness and carrying varying quantities of flint.	

"The most important beds of this series and the ones which would be used in the manufacture of Portland cement are (3) and (5). The principal facts to be determined are the extent and decomposition of the superimposed layers, and therefore the ease and cheapness with which (3) and (5) can be secured. The black slates of the Devonian everywhere fill the valleys in this section and afford very excellent material to combine with the limestone. The following analyses are of the limestones and slates taken from the property adjoining that of the Virginia Portland Cement Company":

Analyses of limestone and shale from near Craigsville.

(Charles Catlett, Analyst.)

	Limestone.	Shale.
	Per cent.	Per cent.
Silica (SiO_2)	0.43	58.07
Alumina (Al_2O_3)	0.21	19.08
Iron oxide (Fe_2O_3)	0.55	6.16
Lime (CaO)	54.55	none
Magnesia (MgO)	0.63	0.64
Volatile matter	43.70	11.17

Other analyses of the limestones and shales at Craigsville, quoted from "The Cement Industry," are as follows:

Analyses of cement materials used at Craigsville, Va.

	Limestone.	Shale.
	Per cent.	Per cent.
Silica (SiO_2)	n. d.	53.63
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3) }	n. d.	24.47
Lime (CaO)	54.30	5.94
Magnesia (MgO)	0.66	1.79
Carbon dioxide (CO_2) } Water }	43.63	10.93

Portions of the Lewistown limestone have been found suitable for marble, and an attempt to use the rock as such has been made at Craigs-

ville and Bells Valley. The strata, however, were found to be unfitted for profitable working. Dr. Henry Froehling gives the following analyses of these rocks in Augusta county:

	I.	II.	III.	IV.
	Per cent.	Per cent.	Per cent.	Per cent.
Calcium carbonate ($CaCO_3$)	95.75	94.95	96.47	96.43
Magnesium carbonate ($MgCO_3$)	1.10	0.29	1.20	0.14
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3) }	1.10	1.80	0.60	1.12
Silica (SiO_2)	0.47	0.20	0.41	0.80
Water and organic matter	1.52	2.60	1.21	1.35
Total	99.94	99.84	99.89	99.84

I. Light gray marble.
II. Dark marble.
III. Dark fossiliferous marble.
IV. Red fossiliferous marble.

Covington.

The more sandy portions, particularly of the Lewistown limestone, are exposed at a number of places along the Chesapeake and Ohio railroad, and vicinity between Covington and Clifton Forge. Some of their strata show a fair cement rock composition according to the following analyses, but others again contain too much arenaceous material to be of use. The rock in this vicinity would, therefore, require careful selection. Shales for mixing are abundant throughout the area.

Analyses of Lewistown limestone, Covington, Va.

(J. H. Gibboney, Analyst.)

	I.	II.
	Per cent.	Per cent.
Insoluble	19.32	48.20
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3) }	1.00	3.80
Lime (CaO)	44.50	18.00
Calcium carbonate ($CaCO_3$)	79.45	32.14
Magnesia (MgO)	0.05	6.89
Magnesium carbonate ($MgCO_3$)	0.12	14.46
Total	99.89	98.60

I. Blue crinoidal limestone.
II. Arenaceous gray limestone.

Clifton Forge.

The greatest development of the Lewistown limestone is in the Clifton Forge area, where R. J. Holden has measured the following section:

Clifton Forge section, Alleghany county.

	Thickness in feet.
Devonian. Shale	?
Oriskany. Thin-bedded sandstone	12
Lewistown:	
Good limestone	3
Sandy limestone	5
Good limestone	15
Limestone with chert nodules	50
Limestone with bryozoa	18
Sandstone	32
Limestone, residual clay with probable limestone	22
Thin-bedded shaly limestone	24
Sandstone	4
Limestone, shaly	11
Total	196

Another section in Alleghany county was measured by Holden as follows:

Section at ford of Potts creek, 0.5 miles above Aritts, Alleghany county.

	Thickness in feet.
Devonian. Shale	?
Oriskany. Sandstone	6
Lewistown:	
Pure limestone (sandy in upper layers)	45
Cherty limestone	55
Massive sandstone	10
Coarse reddish limestone	10
Total	126

Analyses of Lewistown Limestone in Other States.

Extensive outcrops of Lewistown limestone, of which numerous analyses have been made, occur in the states adjoining Virginia. A limestone from Patterson's creek, near Hampshire Furnace, W. Va., is the only one quoted from that state:

Analysis of Lewistown limestone, Patterson's Creek, W. Va.

	Per cent.
Silica (SiO_2)	4.96
Alumina (Al_2O_3) } Iron oxide (Fe_2O_3) }	0.76
Calcium carbonate ($CaCO_3$)	92.44
Magnesium carbonate ($MgCO_3$)	1.40
Water	0.52

The following analyses, quoted from Reports M1, M2, and M3, Second Geological Survey of Pennsylvania, show the variation in composition of these limestones in Pennsylvania:

Analyses of Helderberg limestone, Pennsylvania.

	I.	II.	III.
	Per cent.	Per cent.	Per cent.
Silica (SiO_2)	2.50	1.65	15.72
Alumina (Al_2O_3)	0.84	0.65	2.55
Calcium carbonate ($CaCO_3$)	95.66	96.16	71.73
Magnesium carbonate ($MgCO_3$)	1.55	1.59	7.62
Sulphur (S)	0.10	0.07	n. d.

	IV.	V.	VI.
	Per cent.	Per cent.	Per cent.
Silica (SiO_2)	11.93	20.24	5.94
Alumina (Al_2O_3)	1.36	2.97	1.26
Calcium carbonate ($CaCO_3$)	82.73	73.43	89.39
Magnesium carbonate ($MgCO_3$)	2.83	2.65	3.25
Sulphur (S)	0.70	n. d.	0.27

I. Baker quarry, Altoona, Blair county.
II. Manning quarry, Hollidaysburg, Blair county.
III. Still quarry, 2 miles northeast Montebello Narrows, Perry county.
IV. Van Auken quarry, Middle Smithfield township, Monroe county.
V. Experiment Mills quarry, near Delaware Water Gap, Monroe county.
VI. Poxono Island, Monroe county.

The Helderberg limestone in New York forms a very important source of Portland cement material, and as a result numerous analyses have been published. From these the following have been selected for comparison with the rock of Virginia and contiguous states:

Analyses of Helderberg limestone, New York.

	I.	II.	III.
	Per cent.	Per cent.	Per cent.
Silica (SiO_2)	1.17	5.96	5.66
Alumina (Al_2O_3)	0.64	3.16	2.14
Iron oxide (Fe_2O_3)	0.00	1.34	0.00
Lime (CaO)	54.06	49.70	50.25
Magnesia (MgO)	0.48	1.44	1.11
Carbon dioxide (CO_2)	43.00	40.13	40.70

	IV.	V.	VI.
	Per cent.	Per cent.	Per cent.
Silica (SiO_2)	4.31	1.27	1.89
Alumina (Al_2O_3)	0.97	0.73	1.01
Iron oxide (Fe_2O_3)	0.00	0.00	0.55
Lime (CaO)	51.05	54.51	51.35
Magnesia (MgO)	1.65	0.66	1.67
Carbon dioxide (CO_2)	41.90	43.46	42.19

I. Fogelsonger quarry, Williamsville, Erie county. H. Carlson, analyst. Twentieth Ann. Rept. U. S. Geol. Surv., Pt. 6, p. 427.
II. Strobel quarry, Leroy, Genesee county. Bull. N. Y. State Mus., No. 44, p. 784.
III. Oriskany Falls, Oneida county. A. H. Chester, analyst. Ibid., p. 102.
IV. Cobleskill Quarry Company, Schoharie county. C. F. McKenna, analyst. Twentieth Ann. Rept. U. S. Geol. Surv., Pt. 6, p. 427.
V. Howes Cave, Schoharie county. C. A. Schaeffer, analyst. Ibid., p. 427.
VI. Hudson, Columbia county. Ibid., p. 427.

HANCOCK LIMESTONE.

In the Estillville folio (No. 12) of the U. S. Geological Survey, Mr. M. R. Campbell applied the new name Hancock limestone to the limestone separating the Rockwood formation and the Devonion black shale. As the name indicates, Hancock county, Tennessee, of which Sneedville is the county seat, is the type locality. Previously Professor Safford had named the same formation the Sneedville limestone, although in later publications he adopted the latter term. The Hancock limestone is described as practically limited to the region northwest of Clinch mountain. From a maximum thickness of 275 feet in Powell valley it is said to thin to a feather edge toward the southeast. In lithology the formation is essentially a blue limestone becoming cherty toward the top. In later folios covering the same general area, the Hancock limestone is consistently mapped as such, but proceeding northward a change in the character of sediments is noted, sandy materials succeeding the purer limestones.

In Giles county, Virginia, the sandstones following the limestone become so conspicuous that a new name—the Giles formation—is employed in the Survey folios of the region for the strata between the Rockwood and Devonian black shale. The geologists of the Federal Survey correlate the Hancock limestone with the later Silurian (Meniscus), and the Giles formation with the Lower Helderberg and Oriskany.

The divisions of the typical Sneedville or Hancock limestone are indicated in the following section:

Composite section of Hancock limestone, Hancock county, Tennessee, and Lee county, Virginia.

	Feet.
Devonian (Chattanooga) black shale	——
Silurian (Sneedville or Hancock):	
(i) Rather massive bluish to light gray, slightly magnesian limestone with many of the layers containing over ten per cent. of magnesium carbonate. The only fossil noted is a species of *Stromatopora* ordinarily identified as *Stromatopora concentrica.* This fossil is so abundant that some of the layers are crowded with its masses of concentrically arranged layers three to four inches in diameter. The same species is known in the Manlius at many more northern localities in the Appalachians. Upon weathering these fossils are left as siliceous pseudomorphs strewing the soil	63
(h) Thin layers of fine-grained sandstone and arenaceous limestone. Fossils few or wanting	4
(g) Impure, bluish limestone in thin layers, some of which are made up of a limestone conglomerate of thin, flat pebbles. Upon weathering a few thin chert plates and silicified fossils are left. *Aulopora* sp., *Favosites helderbergiæ* var. *præcedens* Schuchert, *Stromatopora* sp. (*concentrica*), *Halysites* sp. (same species in Coralline limestone of New York and Manlius of Maryland and elsewhere), *Schuchertella interstriatus* (Hall)	20
(f) Nodular clayey limestone with some more even, thin plates of limestone and chert. Fossils abundant in individuals, but few in species. The ostracoda *Klœdenella clarkei* and *Klœdeni manliensis* are unusually abundant, while some slabs are crowded with an undescribed Manlius *Rhynchonella* and a *Meristella*. *Tentaculites gyracanthus*, *Leperditia alta*, and *Megambonia aviculoides* Hall, are represented most numerously among the other identified species	14
(e) Thin-bedded sandstone, the upper part especially full of quartz pebbles, one-eighth inch or less in diameter	4
(d) Mottled arenaceous limestone with one massive layer made up partly of a fine quartz conglomerate. Fossils rather few, *Spirifer vanuxemi* and *Rhynchonella* (?) *litchfieldensis* Schuchert, the only species noted	4
(c) Shaly and nodular clayey limestone holding lenses of purer limestone made up mainly of fossil corals. The fossils in the lenses showed evidence of having been rolled, but in the shaly matrix no signs of this were noted. The fossils are *Bilobites bilobus*, *Plectambonites transversalis*, *Pachydictya crassa*, *Duncanella borealis*, *Streptelasma spongaxis*, *Penniretepora* sp. (same in Brownsport of West Tennessee), *Dalmanella elegantula*, *Heliolites* cf. *micropora*, *Favosites favosus*, *Favosites niagarensis*, *Halysites catenulatus* var., nematoporoid bryozoa with large grooves (same in Brownsport in western Tennessee and Kentucky) *Bythotrypa* cfr. *squamata*, *Eridotrypa* sp., *Fenestella*, and other bryozoans of Niagara affinities. Associated with the above fossils are numerous specimens of a *Favosites* evidently identical with *F. helderbergiæ* var. *præcedens* and several unidentified corals	——

(b) Arenaceous limestone, apparently unfossiliferous 2-3
(a) Conglomerate with quartz pebbles, one-fourth inch or less in diameter .... ¼
Beds a to c are developed only locally, having been noted at a single locality, Sneedville, Tenn.

Rockwood formation:
Yellowish porous sandstone and sandy shales crowded with fossils, of which the ostracod *Beyrichia lata* is the most abundant............. ——

Summing up the evidence in the above section, it would seem that the Hancock (Sneedville) limestone is of late Cayugan (Manlius) age, with locally a conglomerate near its base composed mainly of Niagaran and of a few Manlius fossils. It may be that the upper sixty feet of the section, blue to light gray magnesian limestone, holding *Stromatopora* only, is of Coeymans age, but the evidence in more northern sections seems against this possibility.

Ben Hur, Lee County.

Along the west side of Powell valley, in the section exposed in the foothills of Cumberland mountain, the southernmost exposures of Hancock limestone observed by the writer was at Ben Hur, a station on the Louisville and Nashville railroad, north of Jonesville, Lee county, Virginia. Here most excellent outcrops of the Ordovician and early Silurian formations are shown in the railroad cuts, but unfortunately the later Silurian strata are less favorably exposed. Following are the notes made upon this part of the Ben Hur section.

The thin-bedded reddish to yellow sandstones and purple to green shales of the Rockwood formation are succeeded by 35 to 40 feet of arenaceous limestone, coarse-grained and with small quartz pebbles in the lower part, fine-grained toward the top. No evidence of the upper Niagaran fauna was observed, the lowest fossils being the coral fauna of the early Manlius. *Stromatopora* sp. (*concentrica*), *Favosites helderbergiæ* var. *præcedens* Schuchert, a ramose species of *Favosites*, and the meristelloid brachiopod so abundant at Sneedville, were equally common here.

Above this lower arenaceous portion are possibly 150 feet of drab- to dove-colored, rather massive, impure limestone full of *Stromatopora* sp. (*concentrica*). Associated with these massive limestones were a few thinner bedded strata holding the characteristic Manlius ostracod *Leperditia alta*. The Chattanooga black shale follows the Stromatopora beds, so that the section, excepting the coral lens, is essentially the same as at Sneedville.

Samples for analysis were selected from the exposures of the Hancock limestone just northeast of the station at Ben Hur:

Analyses of Hancock limestone, Ben Hur, Va.

(Wm. M. Thornton, Jr., Analyst.)

	I.	II.	III.
	Per cent.	Per cent.	Per cent.
Silica (SiO_2)	1.80	1.67	3.15
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	0.71	1.06	2.29
Magnesia (MgO)	2.71	2.60	19.04
Lime (CaO)	51.52	51.58	30.84
Magnesium carbonate ($MgCO_3$)	5.66	5.31	39.80
Calcium carbonate ($CaCO_3$)	92.01	92.12	55.08
Total	100.18	100.16	100.32

Big Stone Gap, Wise County.

Proceeding to the head of Powell valley in southwestern Virginia, the Sneedville (Hancock) limestone is found to outcrop over a comparatively large area in the vicinity of Big Stone Gap. The detailed geology of this region is mapped on the Estillville sheet of the U. S. Geological Survey (No. 12). In the short time at the writer's disposal, only a few general notes on the divisions of this limestone were taken, but sufficient evidence was found to show the presence of Manlius strata identical with those of the more southern localities. The rocks referred to this horizon were dark, sandy and impure limestones holding the Manlius brachiopods and corals listed before, as well as the diagnostic ostracods *Leperditia alta* and *Klœdenella clarkei.* Here, however, between the Manlius and the Chattanooga shale, was a development of limestone yielding upon weathering a rather unusual fauna of corals, but with which were associated brachiopods of Coeymans age. A new factor in the study of the formation is thus introduced. Proceeding northward in the Appalachians, still higher Helderbergian strata are found.[a] Here also may be noted thin limestones and shales of the Salina formations underlying the Manlius. These more northern occurrences are noted under the Manlius limestone, and form a separate study of correlation to which Prof. Charles Schuchert has devoted much attention.

[a] Schuchert, Proc. U. S. Nat. Mus., 1903, Vol. XXVI, pp. 413–424.

These figures are copied from various authors. Unless otherwise stated, they are natural size.

Figs. 1–3.—*Spirifer increbescens* (Hall).

1. An individual of the common size but with more extended hinge line than usual.

2, 3. Dorsal and edge views of a rather large example with a shorter hinge line.

Figs. 4, 5.—*Eumetria marcyi* (Shumard). Dorsal and side views of an entire example, somewhat enlarged.

Figs. 6–8.—*Seminula subquadrata* (Hall). Two specimens, natural size, and a side view of one, showing slight variation in the species. Figures 6 and 7 illustrate the subquadrate shape of the specimens.

Figs. 9, 10.—*Seminula trinuclea* (Hall). Dorsal and end views of the same specimen × 2.

Fig. 11.—*Martinia contracta* (Meek and Worthen). Dorsal view of a large specimen.

Figs. 12, 13.—*Productus fasciculatus* (McChesney). Ventral and side views, natural size.

Figs. 14–17.—*Pentremites godoni De France.*

14, 15. Side and basal views of a calyx, natural size.

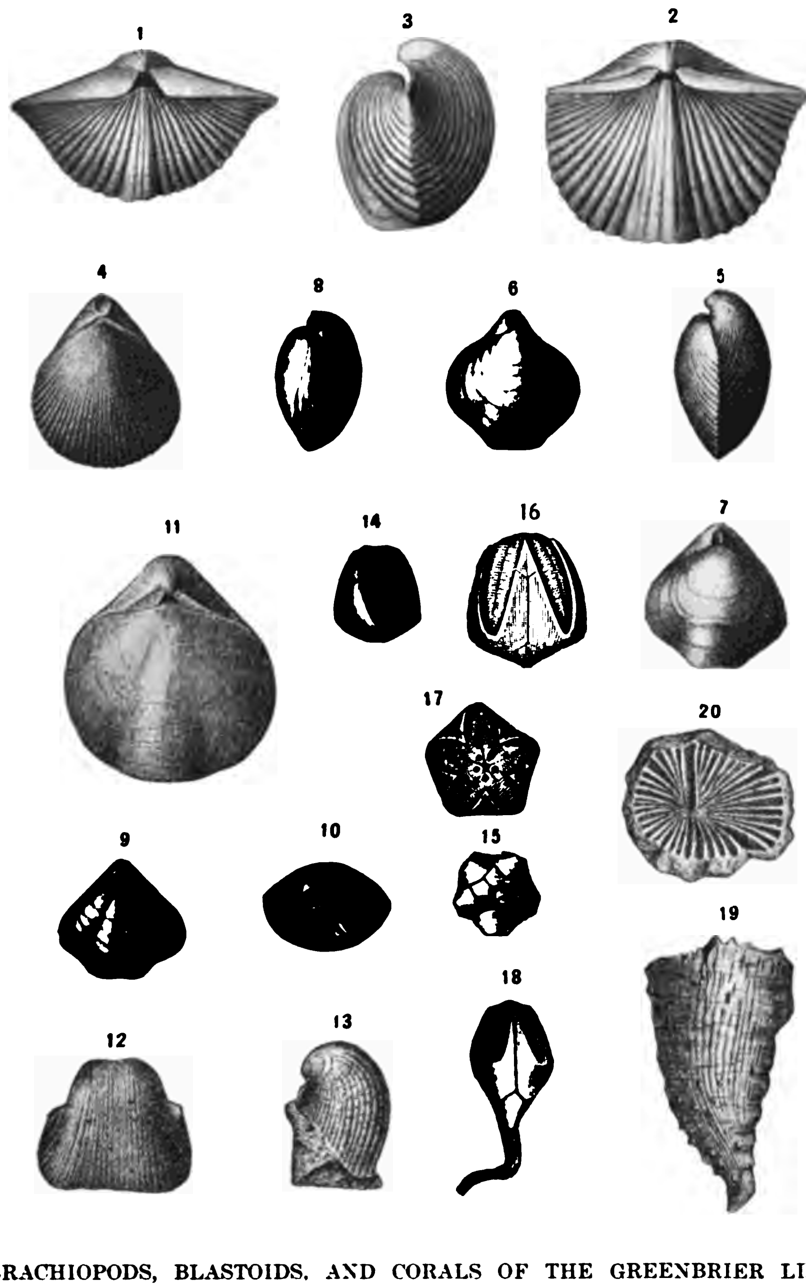
16, 17. Side and summit views of another specimen, slightly enlarged.

Fig. 18.—*Pentremites pyriformis* (Say). Side view of a calyx preserving a portion of the stem.

Figs. 19, 20.—*Zaphrentis spinulosa* (Edwards and Haime).

19. View of a specimen, natural size, showing the spinulose surface.

20. A calyx exhibiting the characteristic fossula.



BRACHIOPODS, BLASTOIDS, AND CORALS OF THE GREENBRIER LIMESTONE.

LURICH SECTION.

Probably the best and most detailed section of the Greenbrier limestone to be observed in Virginia may be seen along the Norfolk and Western railroad near Lurich, in Giles county. Here all of the beds are fairly well exposed and the section may be considered as typical for the region. For this reason all of the variations in the strata at this point were noted and samples taken for analysis. The section is, in ascending order, as follows:

Geologic section, Greenbrier limestone, vicinity of Lurich, Va.

		Feet.
7.	Thin-bedded blue limestone with beds of blue and yellow shale	400
6.	Compact blue to black argillaceous limestone in thin flaggy layers, much fractured	170
5.	Compact blue-black, fine-grained limestone alternating with coarsely crystalline fossiliferous strata, with blue limestone and yellow shales in upper part	150
4.	Drab and blue shales	80
3.	Massive blue and argillaceous limestone with a few shaly beds in the upper part. No chert observed	90
2.	Drab and yellow calcareous shales with occasional bands of compact blue limestone	180
1.	Dark blue to black heavily bedded limestone with many small chert nodules. *Productus*, *Zaphrentis*, and *Fenestella* observed	175

Bed 1.—This, the lowest bed of the Lurich Greenbrier section, is made up of massive limestone containing so many small nodules of chert that its value as a cement rock is small. Selected samples give the favorable analysis shown in I of the table below, but the usual siliceous character of the rock is expressed in II:

Analyses of Greenbrier limestone, bed 1, Lurich, Va., section.

(J. H. Gibboney, Analyst.)

	I.	II.
	Per cent.	Per cent.
Insoluble	8.38	31.82
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	1.20	1.80
Lime (CaO)	49.24	34.90
Calcium carbonate ($CaCO_3$)	87.93	62.32
Magnesia (MgO)	0.80	1.43
Magnesium carbonate ($MgCO_3$)	1.67	2.99
Total	99.18	98.93

I. Dark blue limestone from stratum free from chert nodules.
II. Sample of dark limestone from usual cherty layers.

Bed 2.—The average analysis of the Greenbrier limestone would probably show a lime content too high for a typical cement rock. Therefore the presence of shales in the formation is of importance. The bulk of these shales is contained in this bed, and, as shown below, a considerable variation in composition is encountered. The occasional bands of limestone in the upper part of the bed are finely crystalline, blue fossiliferous strata, high in lime.

Analyses of shales and limestone, bed 2, Lurich, Va., section.

(J. H. Gibboney, Analyst.)

	I.	II.	III.
	Per cent.	Per cent.	Per cent.
Insoluble	47.80	63.40	3.80
Alumina (Al_2O_3) Iron oxide (Fe_2O_3)	4.52	4.52	0.68
Lime (CaO)	23.80	16.54	52.74
Calcium carbonate ($CaCO_3$)	42.86	29.53	94.18
Magnesia (MgO)	1.10	0.83	0.40
Magnesium carbonate ($MgCO_3$)	2.31	1.75	0.84
Total	98.49	99.20	99.50

I. Drab calcareous shales.
II. Yellow shales.
III. Blue fossiliferous limestones.

Bed 3.—All the strata in this bed seemed to be free from chert and to be fairly uniform in composition. The analysis of what was apparently an average sample proved to run higher in silica than the rock otherwise indicated.

Analysis of bluish-black compact limestone, bed 3, Lurich, Va., section.

(J. H. Gibboney, Analyst.)

	Per cent.
Insoluble	8.24
Alumina (Al_2O_3) Iron oxide (Fe_2O_3)	1.04
Lime (CaO)	48.52
Calcium carbonate ($CaCO_3$)	86.64
Magnesia (MgO)	1.87
Magnesium carbonate ($MgCO_3$)	3.92
Total	99.84

Bed 4.—The drab and blue shales comprising this division, although less in thickness, are otherwise quite similar to the shales of bed 2. This

is brought out by the analysis, which is to be compared with No. I of the analyses of bed 2.

Analysis of drab shale, bed 4, Lurich, Va., section.

(J. H. Gibboney, Analyst.)

	Per cent.
Insoluble	41.36
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	4.26
Lime (CaO)	28.80
Calcium carbonate ($CaCO_3$)	51.43
Magnesia (MgO)	1.04
Magnesium carbonate ($MgCO_3$)	2.19
Total	98.24

Bed 5.—This bed consists mainly of compact bluish black, and of coarsely crystalline strata all rather high in lime. Yellow shales are intercalated toward the top of the division, but these form but a small percentage of the total thickness. This bluish black limestone is remarkably similar in composition to the same kind of rock in bed 3. The coarsely crystalline strata are much higher in lime than the more compact rock.

Analyses of limestone, bed 5, Lurich, Va., section.

(J. H. Gibboney, Analyst.)

	I.	II.
	Per cent.	Per cent.
Insoluble	8.42	4.46
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	1.00	1.56
Lime (CaO)	48.56	51.22
Calcium carbonate ($CaCO_3$)	86.71	91.46
Magnesia (MgO)	1.32	0.51
Magnesium carbonate ($MgCO_3$)	2.77	1.08
Total	98.65	98.56

I. Compact bluish black limestone.
II. Coarsely crystalline crinoidal limestone.

Beds 6 and 7.—Thin-bedded limestones and shales compose these two beds, the latter being limited mainly to bed 7. The thin flaggy layers of bed 6 contain more silica than is usually observed in such rocks, but from the field observations the strata as a whole would run lower in this constituent.

Analyses of limestone, beds 6 and 7, Lurich, Va., section.
(J. H. Gibboney, Analyst.)

	I.	II.
	Per cent.	Per cent.
Insoluble	15.10	23.06
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	1.46	2.74
Lime (CaO)	43.84	39.62
Calcium carbonate ($CaCO_3$)	78.28	70.75
Magnesia (MgO)	2.07	0.78
Magnesium carbonate ($MgCO_3$)	4.34	1.64
Total	99.18	98.19

I. Flaggy black limestone of bed 6.
II. Thin-bedded blue limestone of bed 7.

WYTHE COUNTY.

In the discussion of the Ordovician strata in Wythe county, mention was made of the fault bringing the Sevier shale in contact with the Greenbrier limestone, thus placing important cement materials near each other. This area of Greenbrier limestone is crossed by the road from Wytheville to Bland Courthouse, in the northern part of Wythe county. Three samples gave the following upon analysis:

Analyses of Greenbrier limestone, northern part of Wythe county, Virginia.
(J. H. Gibboney, Analyst.)

	I.	II.	III.
	Per cent.	Per cent.	Per cent.
Silica (SiO_2)	5.28	20.90	20.54
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	1.56	0.90	0.70
Lime (CaO)	51.02	42.70	42.94
Calcium carbonate ($CaCO_3$)	91.01	76.25	76.68
Magnesia (MgO)	0.60	0.70	0.36
Magnesium carbonate ($MgCO_3$)	1.26	1.48	0.76
Total	99.11	99.53	98.68

I. Rather pure blue limestone.
II and III. Blue cherty limestone.

ANALYSES FOR COMPARISON.

In Maryland the Greenbrier limestone has been studied and frequently analyzed. A number of these analyses, selected to show variation in the rocks, are given in the following tables:

Analyses of Greenbrier limestone from Maryland.[a]

(T. M. Price, Analyst.)

	I.	II.	III.	IV.	V.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Silica (SiO_2)	13.65	13.46	8.57	20.95	17.00
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	5.44	12.48	2.38	41.10	2.74
Calcium carbonate ($CaCO_3$)	79.16	72.92	88.73	37.35	64.12
Magnesium carbonate ($MgCO_3$)	1.21	1.15	0.86	0.91	15.75

	VI.	VII.	VIII.	IX.	X.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Silica (SiO_2)	4.47	3.65	11.52	5.11	5.24
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	2.70	8.44	3.37	2.56	1.98
Calcium carbonate ($CaCO_3$)	86.73	85.87	74.48	89.08	84.58
Magnesium carbonate ($MgCO_3$)	6.38	1.30	10.99	3.17	7.49

I. Gerringer and Inglehart's quarry, Garrett county.
II. Offutt's quarry, Garrett county.
III. Crabtree, Garrett county.
IV. South of Negro mountain, Garrett county.
V. Offutt's quarry, Garrett county.
VI. Findley's quarry, Piney run, Garrett county.
VII–IX. Mouth of Stony run, Allegany county.
X. Barrellville, Allegany county.

Newman Limestone.

Following the sandstones and sandy shales of Devonian and Mississippian age in southwest Virginia, is a limestone formation showing considerable variability in thickness, this variation ranging from 1,000 to 2,600 feet. To this formation the name Newman limestone has been applied from its outcrop on Newman ridge in Tennessee. The principal areas of outcrop in Virginia have been indicated under the discussion of the Mississippian limestones of the southwestern part of Virginia. The more massive strata of the Newman limestone are characteristic of its lower part, while higher up in the formation considerable calcareous shale deposits are found. Chert likewise is most abundant in the lower strata, although a considerable

[a] Geology of Garrett County, Maryland Geological Surv., pp. 221, 222.

portion of the limestone layers are free from it. Several miles southeast of Mendota, Va., the area of outcrop south of Clinch mountain is traversed by the Virginia and Southwestern railroad, and here for a distance of three or four miles exposures of this limestone may be seen. Two samples, selected with a view to show the variation in the better grade of rock, gave the following upon analysis:

Analyses of Newman limestone, 2 miles southeast of Mendota, Va.

(J. H. Gibboney, Analyst.)

	I.	II.
	Per cent.	Per cent.
Insoluble	7.72	10.40
Alumina (Al_2O_3), Iron oxide (Fe_2O_3)	0.68	0.72
Lime (CaO)	50.20	48.64
Calcium carbonate ($CaCO_3$)	89.64	86.85
Magnesia (MgO)	0.89	0.86
Magnesium carbonate ($MgCO_3$)	1.87	1.71
Total	99.91	99.78

I. Massive blue limestone.
II. Dove-colored limestone.

In the vicinity of Horton Summit, Scott county, a second important area of outcrop is found not far from the tracks of the Virginia and Southwestern railroad. Here, at a point where the railroad cuts through this limestone area, a sample was selected for analysis:

Analysis of dark-blue limestone (Newman), vicinity of Horton Summit, Scott county, Virginia.

(J. H. Gibboney, Analyst.)

	Per cent.
Insoluble	8.56
Alumina (Al_2O_3), Iron oxide (Fe_2O_3)	1.00
Lime (CaO)	49.24
Calcium carbonate ($CaCO_3$)	87.92
Magnesia (MgO)	0.88
Magnesium carbonate ($MgCO_3$)	1.85
Total	99.33

The westernmost outcrops of this limestone follow the eastern front of Stone mountain. Just north of Big Stone Gap a sample was secured for

analysis, while a second sample was taken at Ollinger Gap. The results of these analyses are given below:

Analyses of Newman limestone, southwestern Virginia.

(J. H. Gibboney, Analyst.)

	I.	II.
	Per cent.	Per cent.
Insoluble	7.22	15.82
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	0.41	3.40
Lime (CaO)	50.96	43.98
Calcium carbonate ($CaCO_3$)	91.00	78.54
Magnesia (MgO)	0.65	0.47
Magnesium carbonate ($MgCO_3$)	1.37	0.99
Total	100.00	98.75

I. Dark blue limestone, 1 mile north of Big Stone Gap.
II. Massive blue limestone, Ollinger Gap, Lee county.

The Louisville and Nashville railroad parallels this westernmost branch of outcrop, and at Cumberland Gap crosses it. The following section and analyses published by Mr. Eckel[a] are from the Cumberland Gap district, but the results apply equally well to southwesternmost Virginia.

Geologic section near Cumberland Gap.

	Thickness in feet.
Coal Measures: Shales and sandstones with coal beds.	
Lee conglomerate: Massive sandstone and conglomerate	1,000–1,100
Pennington shale: Greenish shales and thin sandstone	50– 150
Newman limestone: Heavy-bedded blue and gray limestone	250– 400
Grainger shale: Gray to greenish shales	50– 125
Chattanooga shale: Black carbonaceous shales	150– 300
Rockwood formation: Shales and sandstones, with beds of red hematite	400– 700

Quoting Mr. Eckel: "Of the formations above tabulated, the Coal Measures outcrop only in the area northwest of Cumberland mountain. The crest and northwest flank of this mountain are formed by the massive beds of the Lee conglomerate. Underlying the conglomerate, near the top of the southeastern flank of the mountain, is a relatively thin bed of the Pennington shale. Below this, and usually forming the middle part of the

[a]Bulletin No. 285, U. S. Geological Survey, pp. 374–376.

slope, are heavy beds of Newman (Lower Carboniferous) limestone. The Grainger and Chattanooga shales outcrop on the lower slopes of the mountain and in the valley (Poor Valley) at its foot, while the Rockwood beds commonly make up the Poor Valley Ridge just southeast of this valley.

"The Newman (Lower Carboniferous) formation in this district is a series of heavy-bedded blue to gray limestones, the entire section showing a thickness of 250 to 400 feet. Cherty beds occur at several horizons in this limestone, but the mass of the rock is fairly pure and low enough in magnesia to furnish a satisfactory raw material for Portland cement manufacture."

Analyses of limestone near Cumberland Gap, Tenn.

	I.	II.	III.	IV.	V.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Silica (SiO_2)	1.40	1.86	5.05	4.20	2.00
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	1.00	0.96	1.86	1.50	1.00
Lime carbonate ($CaCO_3$)	94.57	94.85	90.05	89.54	94.57
Magnesium carbonate ($MgCO_3$)	3.03	2.33	3.04	4.76	2.50
Sulphur trioxide (SO_3)	n. d.	n. d.	n. d.	n. d.	n. d.
Water	——	——	——	——	——

	VI.	VII.	VIII.	IX.	X.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Silica (SiO_2)	2.80	1.32	4.12	0.74	5.78
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	0.90	1.23	0.42	0.94	0.46
Calcium carbonate ($CaCO_3$)	91.72	95.62	87.10	95.50	90.90
Magnesium carbonate ($MgCO_3$)	4.50	1.32	3.30	2.79	1.46
Sulphur trioxide (SO_3)	n. d.	0.51	n. d.	n. d.	n. d.
Water	——	——	2.21	0.44	1.28

I–VI. Analyses by W. Rosenfeld, chemist Virginia Iron, Coal and Coke Company.
VII. Analysis by L. F. Barnes.
VIII–X. Analyses by J. Sanderson, chemist Watts Iron and Steel Company.

On account of their location, the shales required for mixture can be had in Virginia only from the Pennington, the Grainger, and the Chattanooga divisions of the foregoing section. These three outcrop along the southeastern flank of Cumberland mountain and are frequently approached closely or crossed by the railroad. Notes and analyses of these shales are given in the following paragraphs.

POST-ORDOVICIAN SHALES.

Shaly materials suitable for mixture with limestone in the manufacture of cement occur in the Devonian and Mississippian periods. The Devonian black shale and the Mississippian (Pennington or Bluefield) shales are probably of most value in this connection, although neither formation can be considered of much importance unless well located limestone deposits are close at hand.

Devonian Shales.

Romney or Chattanooga shale.—The use of the Devonian black shale in the making of cement has been noted on a previous page, where also analyses were quoted. The same analyses are given below, and as they seem to represent the usual composition of this material, no samples were selected for further testing.

Analyses of Devonian (Romney) black shale, Craigsville, Va.

	I.	II.
	Per cent.	Per cent.
Silica (SiO_2)	53.63	58.07
Alumina (Al_2O_3)	24.47	19.08
Iron oxide (Fe_2O_3)		6.16
Lime (CaO)	5.94	none
Magnesia (MgO)	1.79	0.64
Volatile matter	10.03	11.17

Sand is rarely present in this shale, and the ratio between silica and iron-alumina falls within the figures necessary in a cement material. Sulphur in the form of iron pyrite is sometimes too abundant, but the great mass of the shale is without this objection.

In the northern portions of western Virginia the Devonian black shale is known under the name of the Romney shale; farther south the name Chattanooga shale has been applied to practically the same formation. In both areas the basal beds are of dark, fissile, carbonaceous shale; higher in the formation, lighter-colored strata predominate.

Many of the valleys west of the Great Valley are underlaid by this black shale. Most of its areas of outcrop have an unproductive soil, giving rise to the various "Poor Valleys" of the Appalachian states.

Grainger formation.—Following these black shales are more sandy shales and finally sandstones of late Devonian age. Only the lowest part of this younger formation is of any importance as a cement material, and probably

the analysis quoted below is exceptional. Reference to the table of formations on page 259 and the columnar section on pages 43, 137, and 139 will show the characters and names of these late Devonian strata.

Analysis of Grainger shale, Cumberland Gap, Tenn.

(J. G. Harding, Analyst.)

	Per cent.
Silica (SiO_2)	74.00
Alumina (Al_2O_3)	13.50
Iron oxide (Fe_2O_3)	3.40
Calcium carbonate ($CaCO_3$)	2.01
Magnesium carbonate ($MgCO_3$)	1.53

Mississippian (Pennington) Shale.

Succeeding the Carboniferous limestones of southwestern Virginia is a shale formation which, in the event of the use of the limestone as a cement material, would be found of importance for mixture. This shale, which in one part of this region has been mapped as the Pennington shale and in another as the Bluefied shale, is, in general, calcareous at the bottom and sandy in its upper part. The lower portions only, therefore, are of importance in the present connection.

The Pennington shale, named from Pennington Gap, in Lee county, is about 1,000 feet thick in its typical area of outcrop. It is made up of calcareous and argillaceous shales with beds of heavy sandstone. The calcareous portions are limited mainly to the base, while the top of the formation is composed of red and purple shales. The formation is well exposed at Big Stone Gap as well as at Pennington Gap.

The possible value of the Pennington shale for mixture with the nearby limestone in cement manufacture is indicated in the following analyses. The samples selected are of the unweathered shale at the type locality:

Analyses of Pennington shale, Pennington Gap, Va.

(Wm. M. Thornton, Jr., Analyst.)

	I.	II.
	Per cent.	Per cent.
Silica (SiO_2)	61.83	55.65
Alumina (Al_2O_3)	18.74	21.43
Iron oxide (Fe_2O_3)	6.73	6.71
Magnesia (MgO)	1.46	1.52
Lime (CaO)	0.40	0.47
Manganese oxide (MnO)	0.02	0.50
Loss on ignition	7.73	10.88
Total	96.41	97.16

In the typical areas of Greenbrier limestone the upper or shaly member of this formation passes gradually into a shale formation named from Bluefield, Mercer county, Virginia. Like the Pennington, the Bluefield shale is composed of calcareous and argillaceous shales with sandstone beds. The more calcareous beds are at the base and the sandy layers are most abundant at the top. Between these extremes is found every variation in composition. The thickness of the Bluefield shale is usually about 1,300 feet.

TRAVERTINE DEPOSITS.

Many of the numerous springs of western Virginia contain carbonate of lime in solution. These have been and are still depositing considerable quantities of calcareous tufa or travertine. Small deposits of such material have been noticed in various parts of this region, and these, if favorably located and in sufficient quantity, would undoubtedly be of much value in cement manufacture. Such materials have been used in the making of Portland cement, although with the abundant limestone of western Virginia, their use is less likely. A noteworthy example of the use of rock material in cement manufacture is at the plant of the Pacific Portland Cement Company in Selano county, California, where travertine and clay are the ingredients mixed. In certain portions of Staunton, Va., as has been noted by Mr. Catlett, the foundations of the houses have been cut in a calcareous marl or travertine 10 or 12 feet deep. An analysis of this deposit is presented below. The surface indications of these travertine deposits are usually not sufficient to estimate the quantity or extent of the rock, and drilling would be necessary to determine these points.

Analysis of travertine, Staunton, Va.

(Charles Catlett, Analyst.)

	Per cent.
Insoluble	5.92
Alumina (Al_2O_3) / Iron oxide (Fe_2O_3)	0.62
Lime (CaO)	50.62
Calcium carbonate ($CaCO_3$)	90.40
Magnesia (MgO)	0.30
Magnesium carbonate ($MgCO_3$)	0.63
Total	97.57

Ellett and Eskridge[a] give the following analyses of calcareous marls or travertine from the Valley region:

[a]Virginia Marls. Bulletin, Virginia Agricultural Experiment Station, 1897, VI (n. s.), 65–70.

Analyses of travertine.

	Frederick County.	Frederick County.	Rockbridge County.	Alleghany County.
Insoluble residue	2.61	3.65	4.34	5.91
Lime (CaO)	52.62	52.19	47.87	50.58
Magnesia (MgO)	0.43	0.44	3.24	0.86
Phosphoric acid (P_2O_5)	0.06	0.36	0.80	0.23
Potash (K_2O)	0.58	0.23	0.31	0.28

Professor Rogers noted these travertine deposits and devoted several pages in his "Geology of the Virginias" to their discussion. The following list quoted from this work (p. 172) gives some of the important localities with the percentage composition of lime carbonate in the deposits:

1. Marl from Tumbling run, 4 miles from Strasburg.
   Carbonate of lime, 84.5 grs. in the 100.
2. Marl from Hite's mill, 3 miles north of Strasburg.
   Carbonate of lime, 87.5 grs.
3. Marl from Flowing Spring run mill, 2½ miles from Charlestown.
   Carbonate of lime, 85.2 grs.
4. Marl from Brook creek, between Strasburg and Woodstock.
   Carbonate of lime, 85.2 grs.
5. Marl from the Opequon, between Winchester and Strasburg.
   Carbonate of lime, 89.07 grs.
6. Marl from 6 miles north of Woodstock.
   Carbonate of lime, 76.3 grs.
7. Marl, same locality.
   Carbonate of lime, 91.0 grs.
8. Marl from Major Stuart's, near Waynesboro.
   Carbonate of lime, 81.8 grs.
9. Marl from White Plains, near Newmarket, substratum in field.
   Carbonate of lime, 85.22 grs.
10. Marl, same locality.
    Carbonate of lime, 79.54 grs.
11. Marl, same locality.
    Carbonate of lime, 76.13 grs.

NATURAL CEMENT.

On a previous page is a discussion by Mr. Eckel of natural cements and their relation to other cements, their manufacture, and the requirements of the raw material. An extended and valuable treatise on this subject is presented by Mr. Eckel in his "Cements, Limes, and Plasters."[a] In the present chapter the writer wishes to point out briefly the distribution of the limestones suitable for this kind of cement, to give analyses, and to indicate the present status of the natural cement industry in Virginia.

Under ordinary circumstances the value of natural cement is too small

[a]Edwin C. Eckel. Cements, Limes and Plasters. Their Materials, Manufacture, and Properties. New York, 1905.

to allow it to be shipped any distance with profit. Therefore the manufacturer must have a home market and little competition. The raw material, as already pointed out by Mr. Eckel, is an argillaceous limestone carrying from 13 to 35 per cent. of clayey material, of which about 10 to 22 per cent. is silica, while alumina and iron oxide together may vary from 4 to 16 per cent. Unlike Portland cement rock, the percentage of magnesium carbonate may run high, the reason for this being that in natural cements the magnesia and lime are regarded as interchangeable. The hydraulic properties do not depend upon the percentage of lime, but upon the clayey materials, which, therefore, are the important factors to consider in the rock analyses. Limestones having a composition within the limits just indicated are more or less abundant at several horizons in western Virginia, but probably the only one which will meet all the requirements and prove of economic importance is the argillaceous magnesian limestone of the lower part of the Shenandoah group. This rock, although often very similar in lithologic characters to the dolomitic limestone found higher in the Shenandoah, can be recognized as containing argillaceous matter by the clayey odor given forth when breathed upon.

These limestones (Shady) and shales (Wautaga) have been described on previous pages, where their use in the making of natural cement was noted. The same strata may be found at various points along the eastern side of the Appalachian Valley, so that a considerable supply of the necessary material should be available.

The clayey magnesian Cambrian limestone used by the James River Cement Company, at Balcony Falls, Rockbridge county, Virginia, in making natural cement, gave the following results upon analyses:

Analyses of natural cement rock, Balcony Falls, Va.

	I.	II.	III.
	Per cent.	Per cent.	Per cent.
Silica (SiO_2)	17.38	17.21	17.30
Alumina (Al_2O_3)	7.80	Tr.	6.18
Iron oxide (Fe_2O_3)		1.62	1.62
Lime (CaO)	34.23	24.85	29.54
Magnesia (MgO)	9.51	16.58	13.05
Carbon dioxide (CO_2)	30.40	37.95	34.17
Cementation index	——	——	1.18

I. E. C. Boynton, analyst. Gillmore. "Limes, Cements, and Mortars," p. 125.
II. C. L. Allen, analyst. "The Virginias," Vol. 3, p. 88.
III. Average of preceding two analyses.

This same belt of magnesian limestones and shales of Cambrian age crosses Virginia into West Virginia and Maryland. Several small natural cement plants have been established in this district at various times, particularly near Antietam, Md., and Shepherdstown, W. Va.

Analyses of natural cements, Shepherdstown-Antietam district, W. Va.-Md.

	I.	II.	III.	IV.
	Per cent.	Per cent.	Per cent.	Per cent.
Silica (SiO_2)	33.42	36.51	33.50	15.97
Alumina (Al_2O_3)	10.04	9.36	10.44	7.59
Iron oxide (Fe_2O_3)	6.00		3.25	
Lime (CaO)	32.79	34.83	29.38	23.72
Magnesia (MgO)	9.59	11.33	13.37	15.6
Alkalies (K_2O, Na_2O)	0.50	1.25	n. d.	n. d.
Sulphur trioxide (SO_3)	n. d.	1.49	1.15	0.71
Carbon dioxide (CO_2) / Water	7.66	5.13	7.15	34.82

I. Shepherdstown, W. Va. Quoted by Cummings. "American Cements," p. 35.
II. Shepherdstown, W. Va. C. Richardson, analyst. Brickbuilder, Vol. 6, p. 229.
III. Antietam, Md. C. Richardson, analyst. Brickbuilder, Vol. 6, p. 229.
IV. Antietam, Md. C. Richardson, analyst. Brickbuilder, Vol. 6, p. 151.

Limestones suitable for natural cement manufacture occur at many places in southwestern Virginia, particularly along the eastern half of the Appalachian Valley. Geologically, these succeed the siliceous deposits of Lower Cambrian age and form the base of the great Shenandoah limestone series. Geographically, however, these particular areas cannot be indicated without detailed mapping requiring long field work. During the progress of his work on the lead and zinc deposits of Virginia, Doctor Watson collected samples of these limestones for analysis. These were published in Bulletin No. 1, "Lead and Zinc Deposits of Virginia," and analyses selected from this publication are quoted below:

Analyses of limestones from Roanoke and Wythe counties.

	I.	II.	III.	IV.
	Per cent.	Per cent.	Per cent.	Per cent.
Insoluble residue	2.90	0.594	0.45	0.20
Silica (SiO_2)	Tr.	0.073	Tr.	Tr.
Titanic acid (TiO_2)	none	none	none	none
Alumina (Al_2O_3)	9.43	0.344	0.24	0.37
Iron oxide (Fe_2O_3)	0.94	0.19	0.17	0.22
Ferrous oxide (FeO)	——	——	——	——
Manganese oxide (MnO)	none	0.193	0.37	Tr.
Lime (CaO)	30.06	29.085	29.50	30.71
Magnesia (MgO)	18.41	20.54	19.93	21.56
Baryta (BaO)	none	none	Tr.	none
Potash (K_2O)	0.24	0.22	0.56	0.12
Soda (Na_2O)	0.21	0.36	1.03	0.10
Water (H_2O) 100°— / Water (H_2O) 100°+	3.30	2.58	3.73	3.92
Carbon dioxide (CO_2)	43.98	45.40	44.01	43.99
Phosphoric oxide (P_2O_5)	none	none	none	none
Sulphur trioxide (SO_3)	none	none	none	none
Total	100.47	99.599	99.99	101.06

I. **Limestone.** Massive grayish-black fine-granular, crushed and recemented with stringers of pure white calcite. Martin property, 2¾ miles southwest of Roanoke city, Roanoke county, Va. Dr. W. E. Barlow, analyst.
II. **Limestone.** Grayish white and moderately coarse crystalline. Specimens taken from the 190-foot level in the Austinville zinc and lead mines, Wythe county, Va. Dr. W. E. Barlow, analyst.
III. **Limestone.** White, coarsely crystalline, and crushed. Specimens taken from the 80-foot level at bottom of open cut, in the Austinville zinc and lead mines, Wythe county, Va. Dr. W. E. Barlow, analyst.
IV. **Limestone.** White and medium crystalline. Specimens taken from the 80-foot level at bottom of open cut, in the Austinville zinc and lead mines, Wythe county, Va. Dr. W. E. Barlow, analyst.

The limestones of most value as natural cement rock received much attention from Professor Rogers, whose analyses have been quoted at various places in the present report. Ten of these analyses are listed in the following table:

Analyses of magnesian limestones in western Virginia.

	I.	II.	III.	IV.	V.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Calcium carbonate ($CaCO_3$)	14.00	13.50	49.00	47.48	13.50
Magnesium carbonate ($MgCO_3$)	10.10	10.63	38.80	45.80	10.56
Alumina (Al_2O_3), Iron oxide (Fe_2O_3)	0.54	0.17	0.84	0.80	0.38
Silica (SiO_2)	4.85	0.60	10.80	5.40	0.39
Water	0.15	0.10	0.56	0.56	0.17
Loss	0.36	——	——	——	——
Total	30.00	25.00	100.00	100.04	25.00

	VI.	VII.	VIII.	IX.	X.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Calcium carbonate ($CaCO_3$)	15.13	14.64	12.33	12.53	9.29
Magnesium carbonate ($MgCO_3$)	11.87	11.24	0.58	8.97	7.31
Alumina (Al_2O_3), Iron oxide (Fe_2O_3)	0.56	0.47	0.57	2.82	1.29
Silica (SiO_2)	2.00	2.88	2.36	0.52	6.93
Water	0.12	0.11	0.16	0.16	0.18
Loss	0.32	0.66	——	——	——
Total	30.00	30.00	25.00	25.00	25.00

I. Light gray, coarse-grained limestone, near Woodstock.
II. Light bluish-gray limestone, 4 miles south of New Market.
III. Bluish-gray, compact limestone, stage road, Shenandoah county.
IV. Crystalline gray limestone, spotted with white, Shenandoah river, Page county.
V. Light gray, subcrystalline limestone, 8½ miles west of Mount Crawford.
VI. Bluish-gray, slaty limestone, 15 miles west of Staunton.
VII. Bluish gray compact limestone, 4 miles west of Staunton.
VIII. Light blue magnesian limestone, near Waynesboro.
IX. Bluish gray limestone, 1½ miles east of Cedar Grove, Rockbridge county.
X. Dark bluish-gray limestone, 8 miles north of Fincastle.

A few of these analyses of the Virginia, Maryland, and West Virginia natural cement rock are listed in the following table for comparison with those of other Appalachian Valley cement rocks:

Analyses of natural cement rocks, Appalachian Valley.

	I.	II.	III.	IV.
	Per cent.	Per cent.	Per cent.	Per cent.
Silica (SiO_2)	17.38	36.51	33.50	22.10
Alumina (Al_2O_3)	7.80	9.36	10.44	5.45
Iron oxide (Fe_2O_3)			3.25	1.80
Lime (CaO)	34.23	34.83	29.38	24.36
Magnesia (MgO)	9.51	11.33	13.37	12.38
Alkalies (K_2O, Na_2O)	——	1.25	n. d.	——
Sulphur trioxide (SO_3)	——	1.49	1.15	——
Carbon dioxide (CO_2)	30.40	5.13	7.15	32.76
Water				1.00
Organic matter	——	——	——	0.15

	V.	VI.	VII.
	Per cent.	Per cent.	Per cent.
Silica (SiO_2)	10.00	27.68	18.34
Alumina (Al_2O_3)	6.10	9.10	7.49
Iron oxide (Fe_2O_3)	2.00	2.52	
Lime (CaO)	30.80	57.96	29.94
Magnesia (MgO)	12.42	2.52	1.55
Alkalies (K_2O, Na_2O)	——	——	——
Sulphur trioxide (SO_3)	——	——	——
Carbon dioxide (CO_2)	37.88	——	32.47
Water	0.30	——	
Organic matter	0.50	——	——

I. Lower Cambrian limestone. Balcony Falls, Va. E. C. Boynton, analyst. Gilmore. "Limes, Cements, and Mortars," p. 125.

II. Lower Cambrian limestone. Shepherdstown, W. Va. C. Richardson, analyst. Brickbuilder, Vol. 6, p. 229.

III. Lower Cambrian limestone. Antietam, Md. C. Richardson, analyst. Brickbuilder, Vol. 6, p. 229.

IV. Conasauga (Cambrian) limestone (siliceous cement part). Cement, Bartow county, Ga. W. J. Land, analyst. Paleozoic Group of Georgia, p. 264.

V. Conasauga (Cambrian) limestone (siliceous hydraulic part). Cement, Bartow county, Ga. W. J. Land, analyst. Paleozoic Group of Georgia, p. 264.

VI. Chickamauga (Ordovician) limestone. Rossville, Ga. Dixie brand. Guild & Co., analysts. Manufacturer's circular.

VII. Trenton (Ordovician) argillaceous limestone. Coplay, Pa. Mineral Industry, Vol. 1, p. 49.

Analyses of other natural cement rocks are quoted below for comparison with those already mentioned:

Analyses of American and European natural cement. (Introduced for comparison.)

	I.	II.	III.	IV.
	Per cent.	Per cent.	Per cent.	Per cent.
Silica (SiO_2)		15.75	18.52	11.50
Alumina (Al_2O_3)	32.00	3.95	6.34	
Iron oxide (Fe_2O_3)		1.00	2.63	1.50
Lime (CaO)	35.28	43.10	25.31	31.75
Magnesia (MgO)	2.00	0.49	12.13	14.91
Alkalies (K_2O, Na_2O)	0.80	——	n. d.	——
Sulphur trioxide (SO_3)	——	0.50	0.90	——
Carbon dioxide (CO_2)	29.92	35.21	33.31	40.34
Water	n. d.		n. d.	——

	V.	VI.	VII.
	Per cent.	Per cent.	Per cent.
Silica (SiO_2)	12.22	13.65	18.33
Alumina (Al_2O_3)	9.39	3.46	4.98
Iron oxide (Fe_2O_3)	3.90	1.45	1.67
Lime (CaO)	24.40	34.55	30.41
Magnesia (MgO)	10.43	7.97	8.04
Alkalies (K_2O, Na_2O)	n. d.	——	——
Sulphur trioxide (SO_3)	n. d.	——	——
Carbon dioxide (CO_2) / Water	38.40	35.92	32.76

I. Sheppey septaria. Redgrave, "Calcareous Cements," p. 49.
II. Representative analysis of "Natural Portland" cement of Belgium.
III. Average analysis of Natural Cement rock (Silurian limestone) in Rosendale district, New York.
IV. Rondout (Silurian) limestone, Howe's Cave, Schoharie county, N. Y. L. C. Beck, analyst. "Mineralogy of New York," p. 79.
V. Ordovician limestone, Utica, Ill. F. W. Clarke, analyst. Sample collected by E. C. Eckel.
VI and VII. Devonian limestone, Louisville district, Indiana-Kentucky. W. A. Noyes, analyst. Quoted by Siebenthal, 25th Ann. Rept. Indiana Dept. Geology and Natural Resources.

CEMENT INDUSTRY IN VIRGINIA.

Although the cement industry may be said to be in its infancy in western Virginia, yet the manufacture of this important economic product has been carried on for many years at one locality, and for a less time at another. Natural cement has been burned near Balcony Falls, Rockbridge

county, for over half a century. The demand for a cheap and trustworthy cement for use in the construction of masonry, locks, and walls on the James River Canal led to the discovery of the hydraulic properties of the rock used at this plant. Since that time a natural cement has been manufactured at this locality almost continuously, the James River Cement Company operating the plant at the present time. The rock used is a steel blue, argillaceous limestone of Lower Cambrian age, with an average thickness of twelve feet. For a description and history of this cement plant, the reader is referred to an anonymous article published in the Engineer, September 29, 1899.

But a single plant for the manufacture of Portland cement is in operation in Virginia, namely, that of the Virginia Portland Cement Company at Craigsville, Augusta county. The geologic section at Craigsville and analyses of the rock employed have been given on a previous page. As the methods employed by the Virginia Portland Cement Company are those of a large, modern plant, a description of the process of manufacture is here introduced.

The materials used in the manufacture of the Old Dominion cement are Lewistown limestone and shale. The principal limestone quarry is located a mile and one-eighth from the plant, and the shale quarry three-quarters of a mile.

The shale is crushed at the quarry and brought down on a standard gauge track to the scale house, where it is elevated into bins over the scales.

The limestone is brought to the scale house on a narrow gauge track in cars containing about 3,000 pounds of limestone. The limestone cars are weighed and the proper percentage of shale is dropped from the bins onto the limestone, and the narrow gauge car is then picked up by a cable and carried to a 7½ Gates crusher, through which the limestone and shale pass together.

The output of the crusher goes through a revolving screen and the rejections from the screen are passed through a No. 3 crusher. From the crushers, the raw material is elevated on a belt conveyer to 12 tanks, containing about 70 tons each. The material is drawn from the bottom of these tanks into a belt conveyer, which carries it to the rotary dryers, 3 in number. From the dryers, the material is carried on a belt conveyer to the raw material mill, where it receives its preliminary grinding in ball mills, and its fine grinding in pebble mills. The outfit of this raw material mill consists of 3 Krupp ball mills, 2 Smidth komminuters, 3 Krupp pebble mills, and 3 Smidth pebble mills.

Old Dominion Portland Cement Mill, Craigsville.

The ground material is conveyed by means of belt conveyers, elevators and screw conveyers to tanks over the kilns, and is fed into the kilns by conveyers in the bottom of tanks. The rotary kilns are 10 in number, 60 feet long, 6 feet in diameter, slightly inclined from the feed end to the discharge end. Powdered coal is used as fuel for burning the raw material. It is blown in by a low pressure blast of air and ignites instantly. The heat generated is about 2,600°. The coal is first dried in rotary dryers and passed through pebble mills, similar to those used for grinding the raw material.

The material passes from the kilns in the form of clinker and is elevated into coolers through which a blast of air is forced. From the bottom of the coolers, it is drawn by means of a belt conveyer to the clinker storage, where it is allowed to age for about three weeks. Underneath the floor of the clinker storage are belt conveyers, which convey the clinker to the cement mill.

The process in the cement mill is a repetition of that in the raw material mill. The cement grinding machinery consists of 2 Krupp ball mills, 3 Smidth komminuters, 2 Krupp pebble mills, and 4 Smidth pebble mills. From the cement mill the finished cement is conveyed by belt conveyers to the 2 stockhouses, where it is stored in bins until such time as it is shipped out. The cement is drawn from the bins into screw conveyers, elevated into bins over the bag packers and barrel packers. The bag packers are operated by hand and the barrels are packed by power.

The storage capacity is 100,000 barrels. The present output of the plant is between 1,800 and 1,900 barrels per day. Construction work is at present under way to increase the capacity of the plant to 3,000 barrels per day.

The power equipment of the plant includes 8 Sterling water tube boilers, 1 Hamilton Corliss engine of 750 H. P., 1 Copper Corliss engine of 1,100 H. P., and 1 Westinghouse engine of 250 H. P. Electric generators located in the power house furnish current to motors which operate the kilns and a large part of the conveying machinery. The grinding machinery is belted to shafting.

As the mill is located so far away from any city, it was necessary for the company to provide homes for its employees. The company has accommodations for some 200 families, runs a commissary store, village water works, etc. The company employs a physician, maintains a hospital, and close attention is paid to sanitary inspection. The number of employees is about 425.

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Reports treating of the limestones and shales of Virginia with reference to their use as cement materials have been few. Numerous papers treating of the geology of Appalachian Virginia, particularly of the southwestern part, have been published, but few of these have direct bearing on, or are of use in, the location of cement rock. Those which may be found of value in this respect are noted in the following bibliographic list.

The U. S. Geological Survey has mapped all of western Virginia geographically, this area being included in 27 quadrangles. However, only 8 folios of the Geologic Atlas of the United States touching this region have been published. These are the Harpers Ferry folio for northwestern Virginia; the Staunton, Franklin, and Monterey folios for central western Virginia; and the Pocahontas, Tazewell, Bristol, and Estillville folios for southwestern Virginia. These folios contain topographic sheets, areal and economic geologic sheets, and structure sections of the areas studied, with text descriptions of the geology and mineral resources. However, only the 4 last mentioned give maps in which the argillaceous and pure limestones of Ordovician age are separated from the impure Cambro-Ordovician series.

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